Flavour Physics

Irina Nasteva
Universidade Federal do Rio de Janeiro
on behalf of the LHCb collaboration, with results from ATLAS and CMS

Outline

Why is flavour physics important?

A selection of recent LHC flavour physics results:

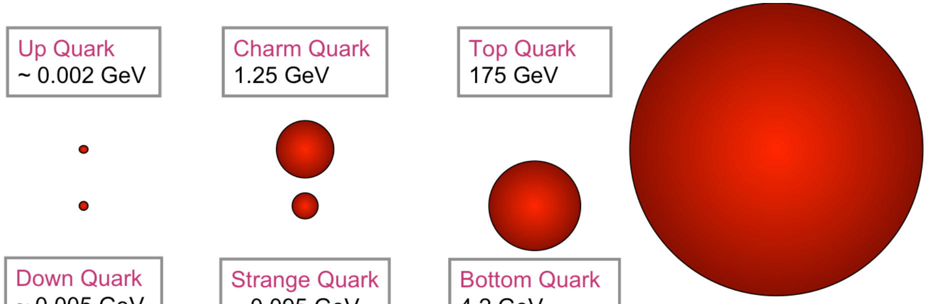
- CP violation in beauty and charm
- Rare decays
- Lepton flavour universality

Why flavour physics?

The origin of flavour is one of the big unsolved mysteries in fundamental physics.

The SM describes flavour accurately, but it does not explain:

- Why 3 generations of quarks?
- Why do fermions have such an extreme mass hierarchy?



- What determines the elements of the CKM matrix?
- What is the origin of matter-antimatter asymmetry? SM-level CP violation is insufficient to explain it.

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 0.9705-0.9770 & 0.21-0.24 & 0-0.014 \\ 0.21-0.24 & 0.971-0.973 & 0.036-0.070 \\ 0-0.014 & 0.036-0.070 & 0.997-0.999 \end{pmatrix}$$

Flavour physics as probe for New Physics

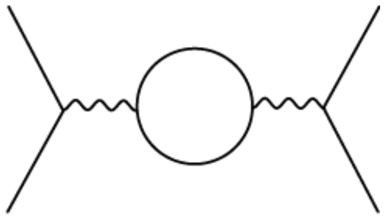
The SM could be a low-energy effective theory of a more fundamental theory at a higher energy scale, introducing new symmetries, dynamics and particles.

NP searches − the energy frontier:

- New particles produced and observed *as real particles* at energy frontier machines (LHC).

NP searches − the intensity frontier:

- New particles appear *as virtual particles* in loops, leading to observable differences from SM expectations.

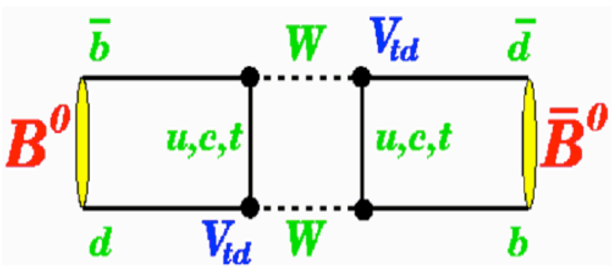


BSM theories face many challenges to prove compatible with experimental constraints on flavour observables.

Discovery potential of indirect searches

Neutral B-meson oscillations gave the first evidence for a large top quark mass.

- A heavy top appears in the loop.



OBSERVATION OF B^0–$\bar{B}^0$ MIXING

ARGUS Collaboration

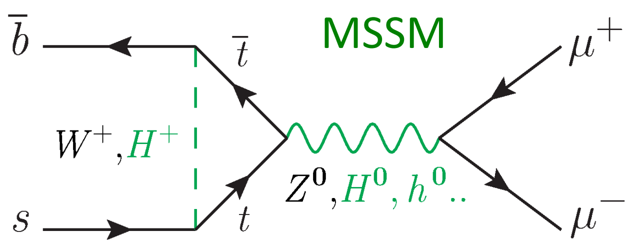
In summary, the combined evidence of the investigation of B^0 meson pairs, lepton pairs and B^0 meson–lepton events on the Υ(4S) leads to the conclusion that B^0–$\bar{B}^0$ mixing has been observed and is substantial.

Parameters	Comments
$r > 0.09$ (90%CL)	this experiment
$x > 0.44$	this experiment
$B^{1/2} f_B \approx f_\pi < 160$ MeV	B meson ($\approx$pion) decay constant
$m_b < 5$ GeV/c^2	b-quark mass
$\tau < 1.4 \times 10^{-12}$s	B meson lifetime
$\lvert V_{td} \rvert < 0.018$	Kobayashi–Maskawa matrix element
$\eta_{QCD} < 0.86$	QCD correction factor [a)]
$m_t > 50$ GeV/c^2	t quark mass

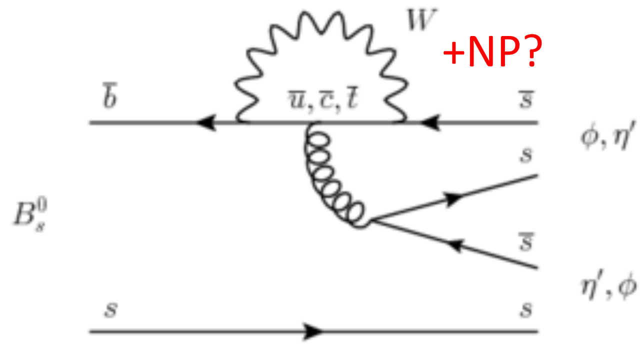
Phys. Lett. B192, 245 (1987)

Flavour physics as probe for New Physics

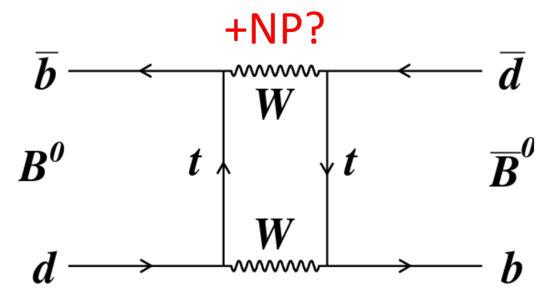
Search for deviations from the SM predictions due to new heavy particles in loop processes.



$B_s \to \mu\mu$



$B_s \to \phi\phi$ (penguin)



$B^0 - \bar{B}^0$ mixing (box)

Measure with high precision:

- CP-violating and flavour-changing processes.
- Rare decays of heavy quarks.

Compare to precise SM predictions – need theoretically clean observables.

Can look for new symmetries and probe mass scales beyond those accessible in direct production.

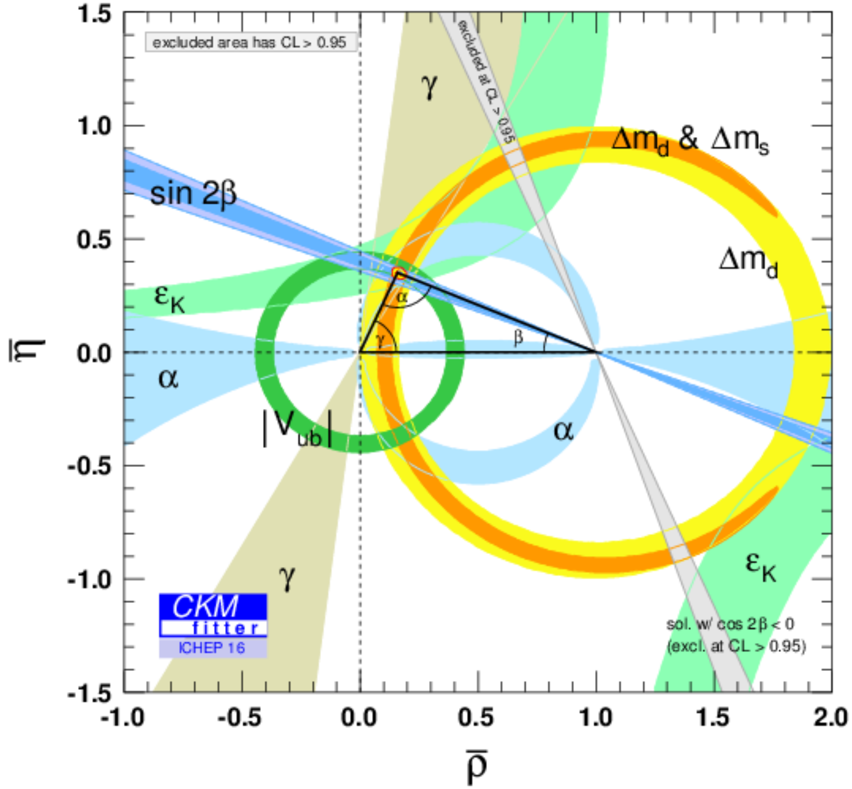
CP violation in beauty and charm

See also talks on:

- $D \rightarrow hhh$ amplitude analysis – Fernanda Gonçalves
- $B_c \rightarrow hhh$ decays – Leandro de Paula
- CP violation in $B \rightarrow hhh$ – I.N.

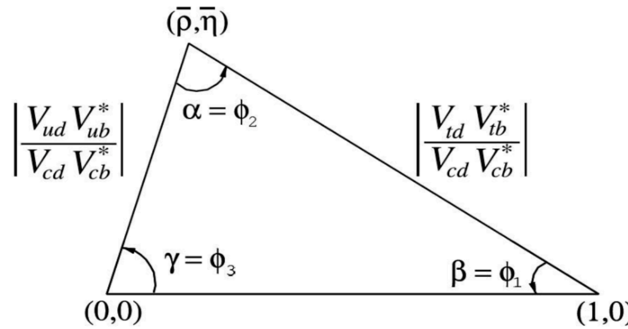
CP violation – the unitarity triangle

http://ckmfitter.in2p3.fr



flavour states CKM matrix mass states

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



B_d mixing phase: $\phi_d = 2\beta = -\arg(V_{td}^2)$
B_s mixing phase: $\phi_s = -2\beta_s = -\arg(V_{ts}^2)$
weak decay phase: $\gamma = -\arg(V_{ub})$

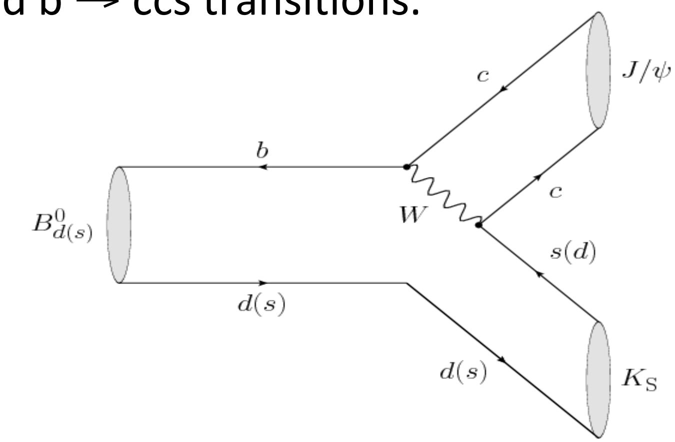
Experimental confirmation of CKM model as dominant source of CP violation.

- Measurements of the sides and angles.
- Any inconsistency will be a sign of New Physics.
- Experimental progress: increased precision.

Measurement of sin(2β)

CP violation due to interference between B^0-$\overline{B}^0$ mixing and $b \to c\bar{c}s$ transitions.

$$\beta \equiv \arg[-(V_{cd}V_{cb}^*)/(V_{td}V_{tb}^*)]$$

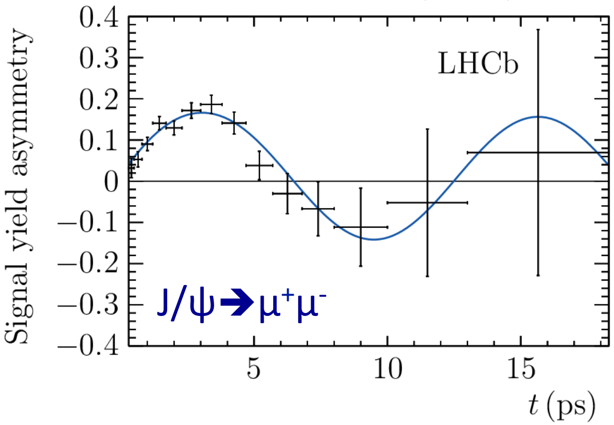


- The golden channel is $B^0 \to J/\psi\, K_S$.
- Also $B^0 \to \psi(2s)K_S$ with $J/\psi \to \mu^+\mu^-(e^+e^-)$, $K_S \to \pi^+\pi^-$.
- Flavour tagging of B^0 at production.
- Time-dependent signal yield asymmetry:

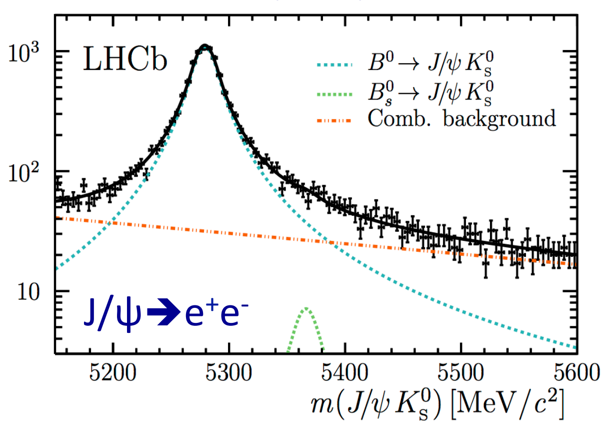
$$\mathcal{A}(t) \equiv \frac{\Gamma(\overline{B}^0(t) \to J/\psi\, K^0_S) - \Gamma(B^0(t) \to J/\psi\, K^0_S)}{\Gamma(\overline{B}^0(t) \to J/\psi\, K^0_S) + \Gamma(B^0(t) \to J/\psi\, K^0_S)} = \frac{S\sin(\Delta m\, t) - C\cos(\Delta m\, t)}{\cosh(\frac{\Delta\Gamma\, t}{2}) + A_{\Delta\Gamma}\sinh(\frac{\Delta\Gamma\, t}{2})}$$

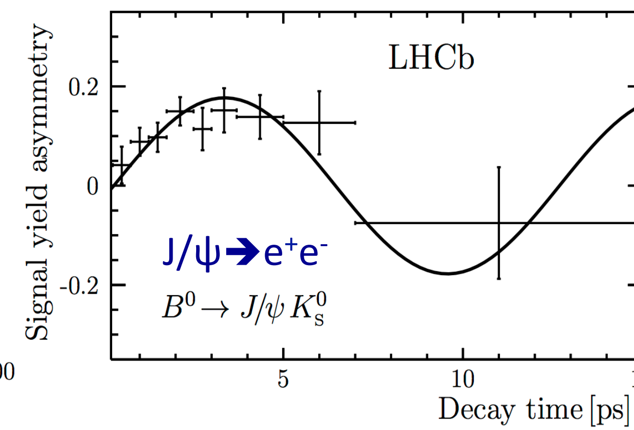
where S ≈ sin(2β)

PRL 115, 031601 (2015)



JHEP 11, 170 (2017)

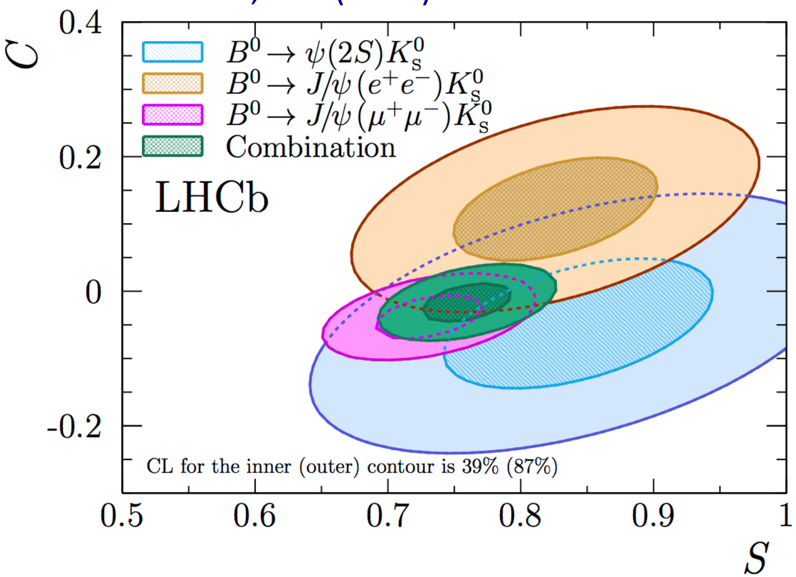


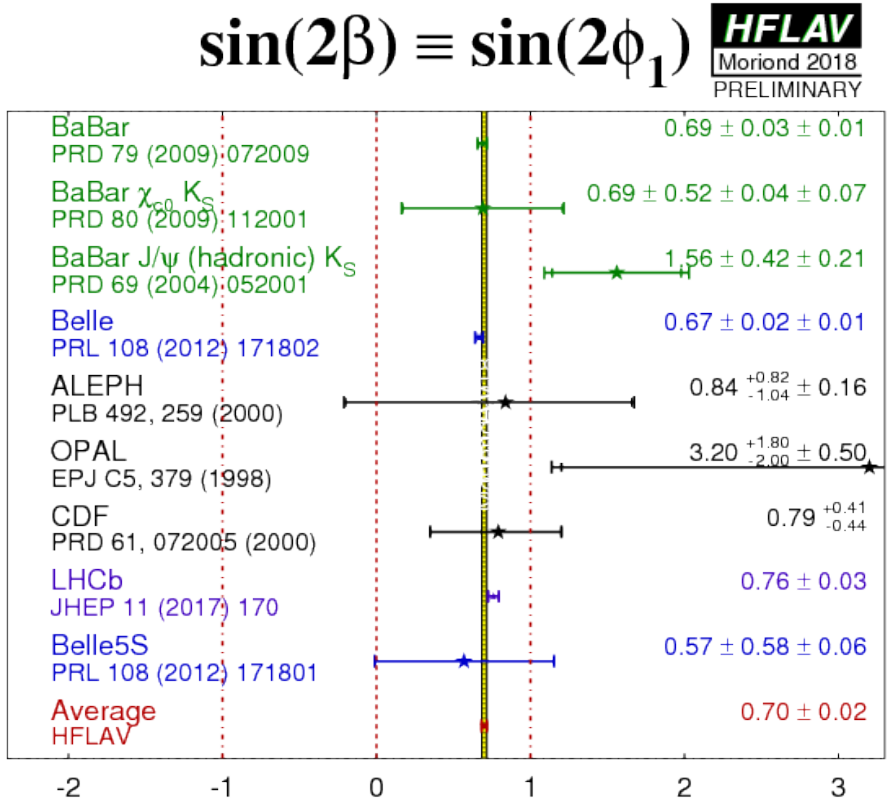


Measurement of sin(2β)

- LHCb average with 3 fb^{-1} data: $S = \sin(2\beta) = 0.760 \pm 0.034$
- Precision comparable to B factories, will surpass them with Run-2 data.
- Consistent with indirect measurements and SM.

JHEP 11, 170 (2017)





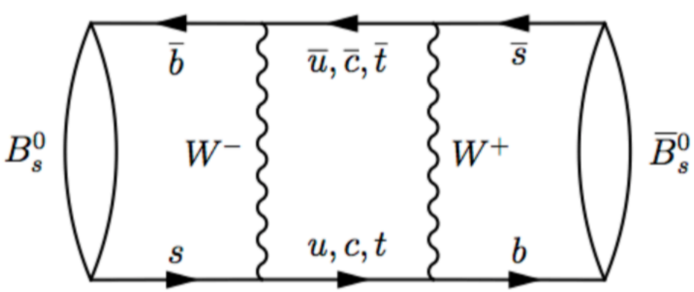
- ATLAS showed that $\Delta\Gamma_d$ is small:

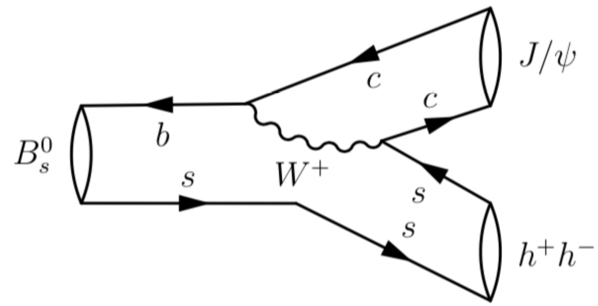
$$\Delta\Gamma_d/\Gamma_d = (-0.1 \pm 1.1\ (\text{stat.}) \pm 0.9\ (\text{syst.})) \times 10^{-2}$$

JHEP 06, 081 (2016)

Measurement of ϕ_s

CPV phase in interference between B_s^0-$\bar{B}_s^0$ mixing and tree-dominated $b \rightarrow c\bar{c}s$ transitions.





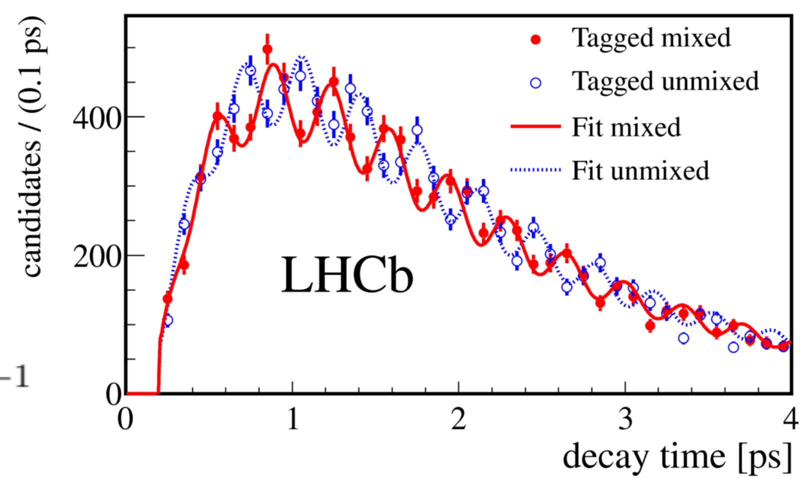
$$\phi_s \equiv -2\beta_s = -2\arg\left(-\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}\right)$$

- A deviation from the SM prediction could signal NP particles in the mixing loop.

- The golden channel is $B_s^0 \rightarrow J/\psi\ \phi$.
- Angular analysis to disentangle CP eigenstates in final state with two vectors.
- Requires excellent B tagging and decay time resolution.
- B_S^0 has fastest oscillations.

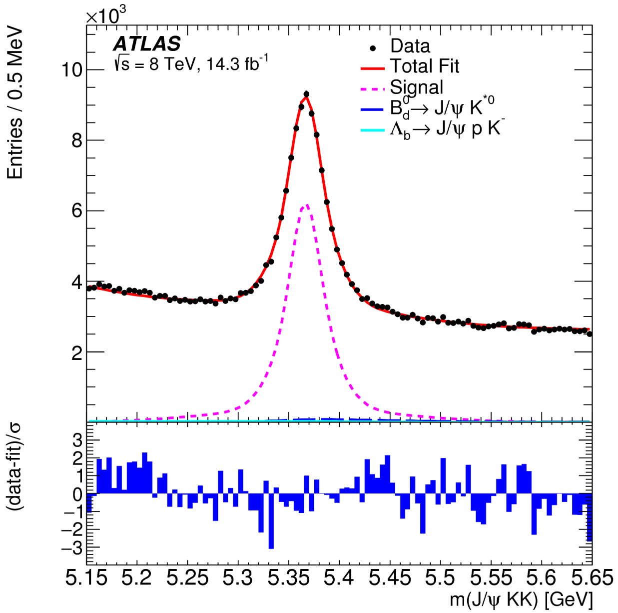
$$\Delta m_s = 17.768 \pm 0.023\ (\text{stat}) \pm 0.006\ (\text{syst})\ \text{ps}^{-1}$$

New J. Phys. 15 053021 (2013)

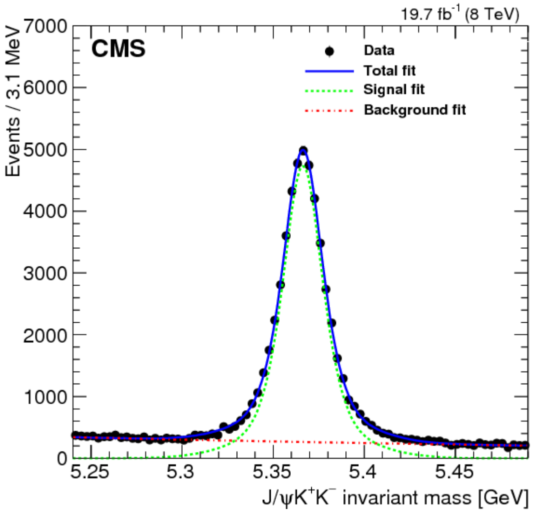


Measurement of ϕ_s

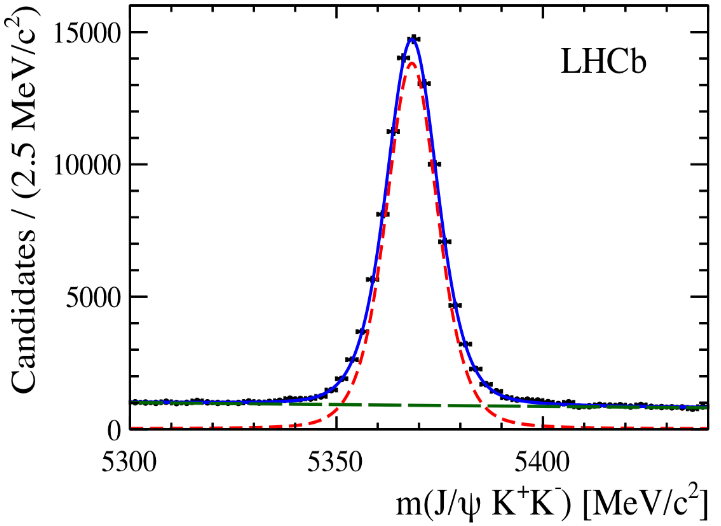
LHC-wide experimental effort:



JHEP08 (2016) 147
ATLAS: 75k candidates



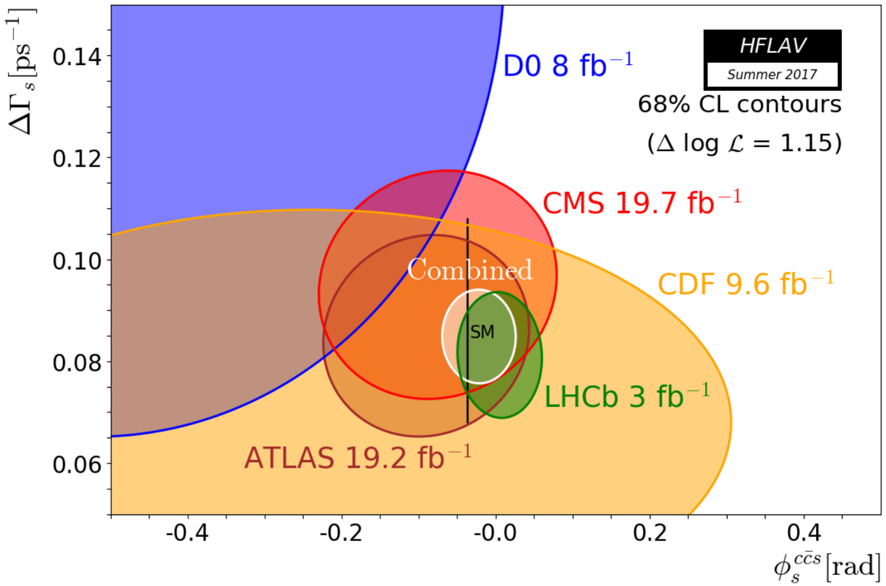
Phys. Lett. B757 (2016) 97
CMS: 49k candidates



PRL 114 (2015) 041801
LHCb: 95k candidates

- All based on Run-1 data.
- Full test of flavour-tagging abilities and detector resolutions.

Measurement of ϕ_s



- LHCb measurement of -10 ± 39 mrad dominates the global fit.
- World average -21 ± 31 mrad.
- So far consistent with the SM, precision will improve with Run-2 data.
- Need to control penguin contributions.

http://www.slac.stanford.edu/xorg/hflav/

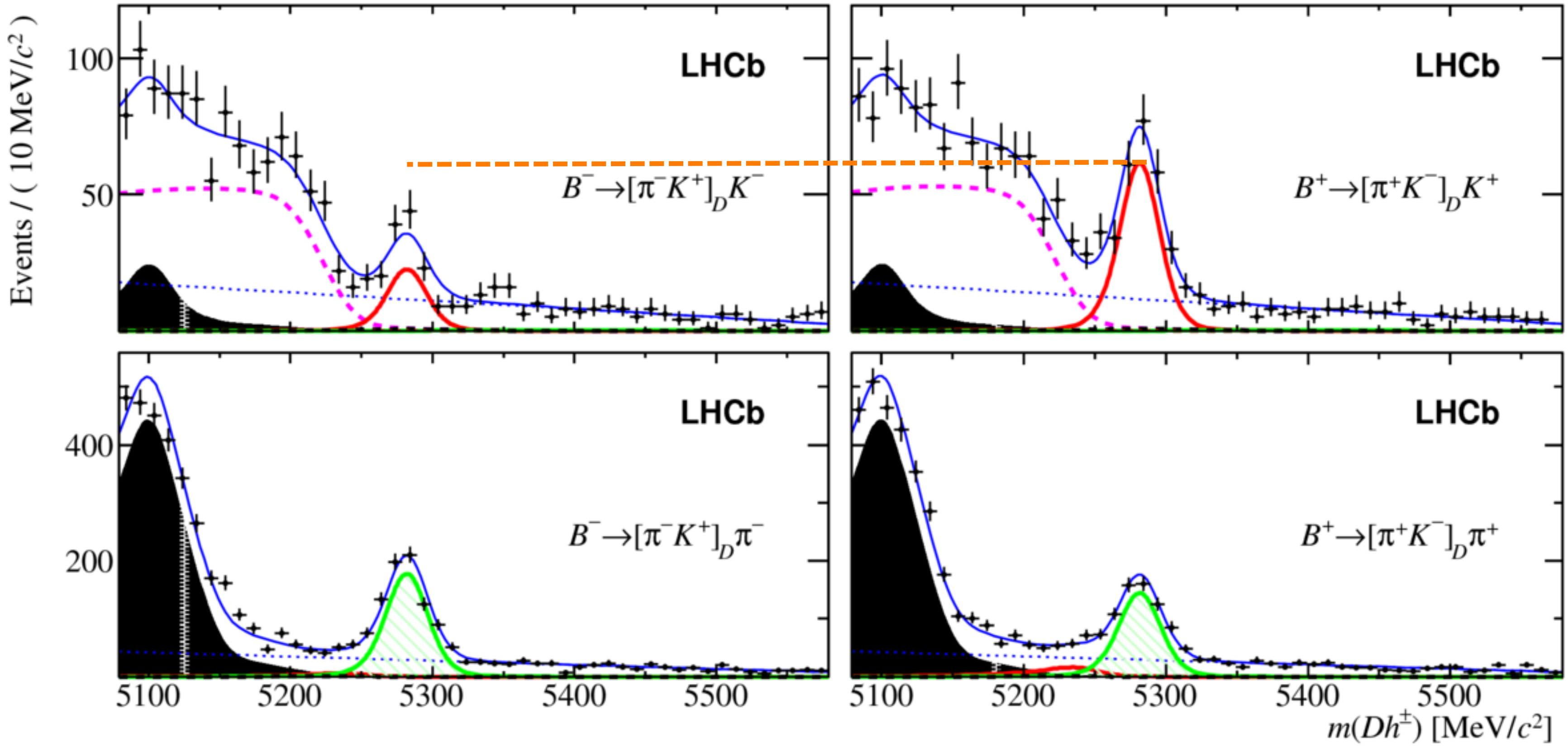
Exp.	Mode	Dataset	$\phi_s^{c\bar{c}s}$	$\Delta\Gamma_s$ (ps^{-1})	Ref.
CDF	$J/\psi\,\phi$	9.6 fb^{-1}	$[-0.60, +0.12]$, 68% CL	$+0.068 \pm 0.026 \pm 0.009$	[2]
D0	$J/\psi\,\phi$	8.0 fb^{-1}	$-0.55^{+0.38}_{-0.36}$	$+0.163^{+0.065}_{-0.064}$	[3]
ATLAS	$J/\psi\,\phi$	4.9 fb^{-1}	$+0.12 \pm 0.25 \pm 0.05$	$+0.053 \pm 0.021 \pm 0.010$	[4]
ATLAS	$J/\psi\,\phi$	14.3 fb^{-1}	$-0.110 \pm 0.082 \pm 0.042$	$+0.101 \pm 0.013 \pm 0.007$	[5]
ATLAS	above 2 combined		$-0.090 \pm 0.078 \pm 0.041$	$+0.085 \pm 0.011 \pm 0.007$	[5]
CMS	$J/\psi\,\phi$	19.7 fb^{-1}	$-0.075 \pm 0.097 \pm 0.031$	$+0.095 \pm 0.013 \pm 0.007$	[6]
LHCb	$J/\psi\,K^+K^-$	3.0 fb^{-1}	$-0.058 \pm 0.049 \pm 0.006$	$+0.0805 \pm 0.0091 \pm 0.0032$	[7]
LHCb	$J/\psi\,\pi^+\pi^-$	3.0 fb^{-1}	$+0.070 \pm 0.068 \pm 0.008$	—	[8]
LHCb	$J/\psi\,K^+K^{-a}$	3.0 fb^{-1}	$+0.119 \pm 0.107 \pm 0.034$	$+0.066 \pm 0.018 \pm 0.010$	[9]
LHCb	above 3 combined		$+0.001 \pm 0.037$(tot)	$+0.0813 \pm 0.0073 \pm 0.0036$	[9]
LHCb	$\psi(2S)\phi$	3.0 fb^{-1}	$+0.23^{+0.29}_{-0.28} \pm 0.02$	$+0.066^{+0.41}_{-0.44} \pm 0.007$	[10]
LHCb	$D_s^+D_s^-$	3.0 fb^{-1}	$+0.02 \pm 0.17 \pm 0.02$	—	[11]
All combined			-0.021 ± 0.031	$+0.085 \pm 0.006$	

Measurement of γ

- Least well constrained angle in the CKM triangle. $\gamma \equiv \arg\left[-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*\right]$
- Clean measurement using $b \to u$ and $b \to c$ tree-level transitions, SM only.
- For example, favoured and suppressed "ADS" mode: $B^- \to D^0(\pi^- K^+)h^-$:

$$\mathcal{A}_{\text{sup}}/\mathcal{A}_{\text{fav}} = r_B^X e^{i(\delta_B^X \pm \gamma)}$$

Phys. Lett. B760, 117 (2016)



Measurement of γ

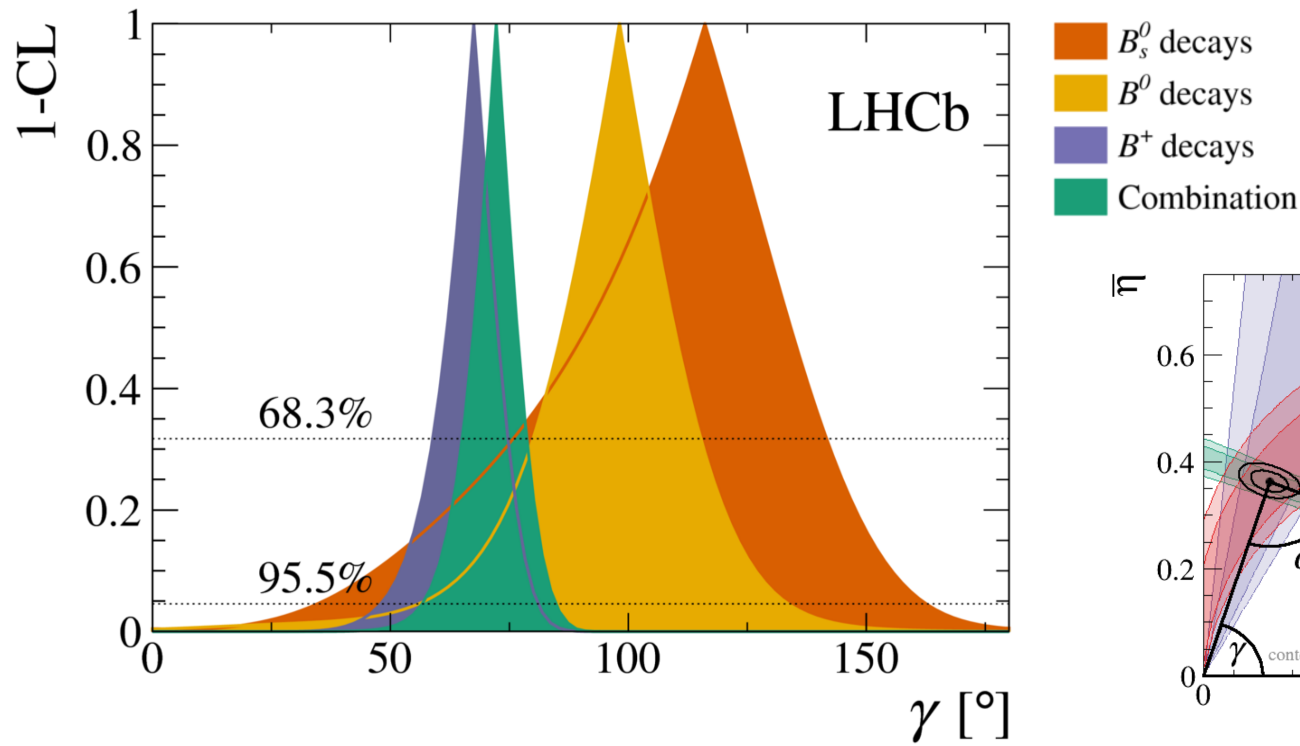
- LHCb measurement is a combination of many independent analyses:

B decay	D decay	Method	Ref.	Status since last combination [1]
$B^+ \to DK^+$	$D \to h^+h^-$	GLW	[16]	Updated to Run 1 + 2 fb^{-1} Run 2
$B^+ \to DK^+$	$D \to h^+h^-$	ADS	[17]	As before
$B^+ \to DK^+$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS	[17]	As before
$B^+ \to DK^+$	$D \to h^+h^-\pi^0$	GLW/ADS	[18]	As before
$B^+ \to DK^+$	$D \to K^0_S h^+h^-$	GGSZ	[19]	As before
$B^+ \to DK^+$	$D \to K^0_S K^+\pi^-$	GLS	[20]	As before
$B^+ \to D^*K^+$	$D \to h^+h^-$	GLW	[16]	New
$B^+ \to DK^{*+}$	$D \to h^+h^-$	GLW/ADS	[21]	New
$B^+ \to DK^+\pi^+\pi^-$	$D \to h^+h^-$	GLW/ADS	[22]	As before
$B^0 \to DK^{*0}$	$D \to K^+\pi^-$	ADS	[23]	As before
$B^0 \to DK^+\pi^-$	$D \to h^+h^-$	GLW-Dalitz	[24]	As before
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	GGSZ	[25]	As before
$B^0_s \to D_s^{\mp}K^{\pm}$	$D_s^+ \to h^+h^-\pi^+$	TD	[26]	Updated to 3 fb^{-1} Run 1

LHCb-CONF-2017-004

85 observables and 37 free parameters

Measurement of γ



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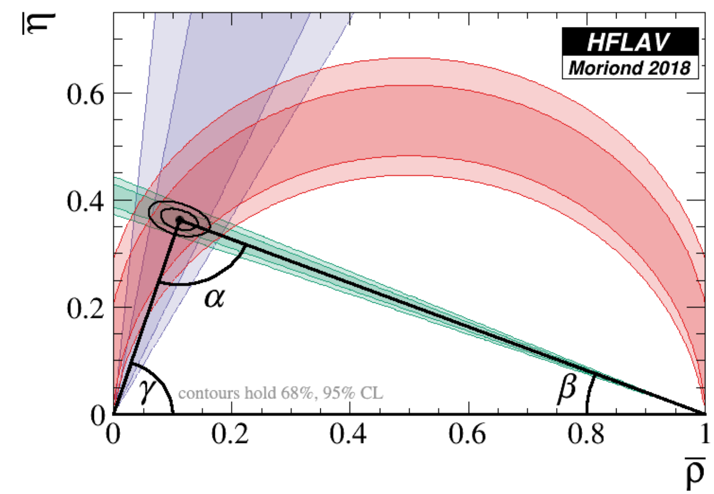


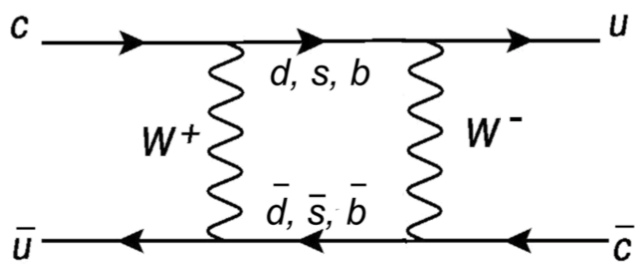
- LHCb reached 5° uncertainty, significantly better than B factories.

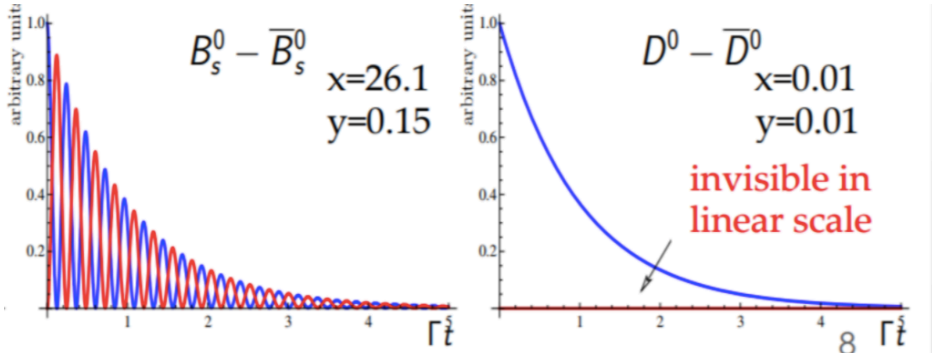
$$\gamma = (76.8\,^{+5.1}_{-5.7})^\circ$$

- Agrees with prediction from the rest of CKM triangle: $\gamma^{\text{indirect}} = (65.3\,^{+1.0}_{-2.5})^\circ$

CP violation in charm

Measurement of D^0-$\overline{D}^0$ mixing and CP-violation parameters.





- Mass eigenstates are linear combinations of flavour eigenstates:

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

- if p ≠ q, CP violation in the mixing.

- Mixing parameters:

$$x = 2(m_2 - m_1)/(\Gamma_1 + \Gamma_2)$$
$$y = (\Gamma_2 - \Gamma_1)/(\Gamma_1 + \Gamma_2)$$

- Negligible CP violation predicted by the SM for charm ($<10^{-3}$ in mixing).
- Measure the CP-averaged decay-time-dependent ratio of wrong-sign ($D^0 \to K^+\pi^-$ from doubly Cabibbo-suppressed and oscillated D^0) to right-sign (Cabibbo-favoured $D^0 \to K^-\pi^+$) decay rates:

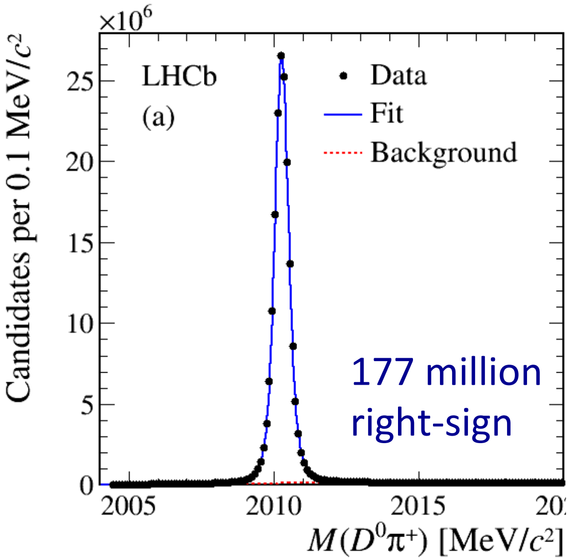
$$R(t) \approx R_D + \sqrt{R_D}y'\frac{t}{\tau} + \frac{x'^2 + y'^2}{4}\left(\frac{t}{\tau}\right)^2$$

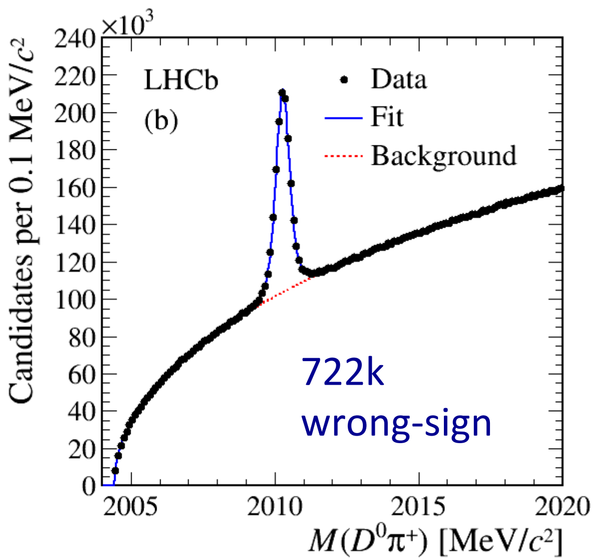
CP violation in charm

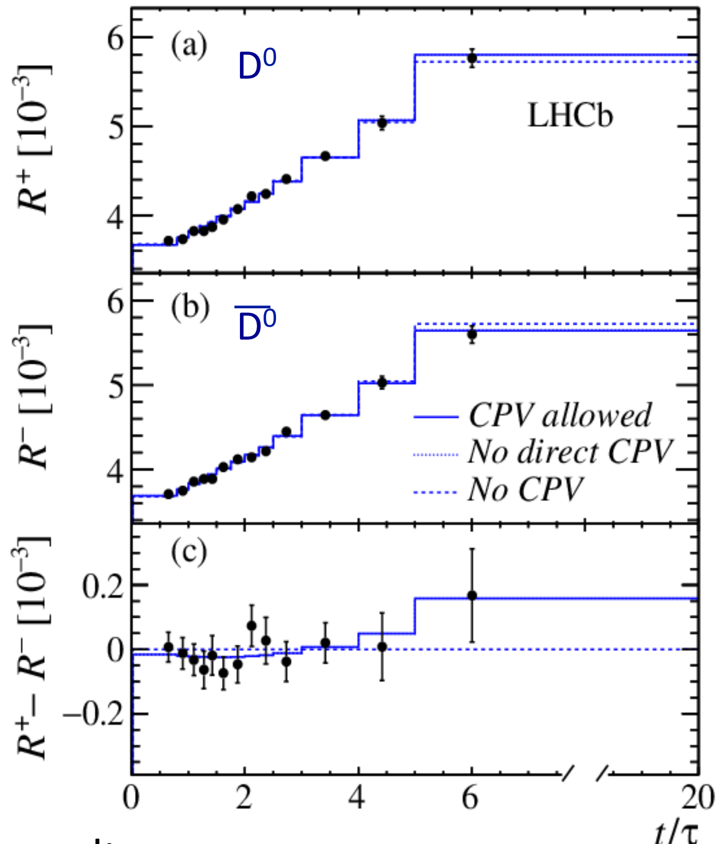
Measurement of D^0-$\overline{D}^0$ mixing and CP-violation parameters.

- LHCb Run-1 and Run-2 sample is largest ever.

Phys. Rev. D97 031101 (2018)







$$x'^2 = (3.9 \pm 2.7) \times 10^{-5}$$

$$y' = (5.28 \pm 0.52) \times 10^{-3}$$

$$R_D = (3.454 \pm 0.031) \times 10^{-3}$$

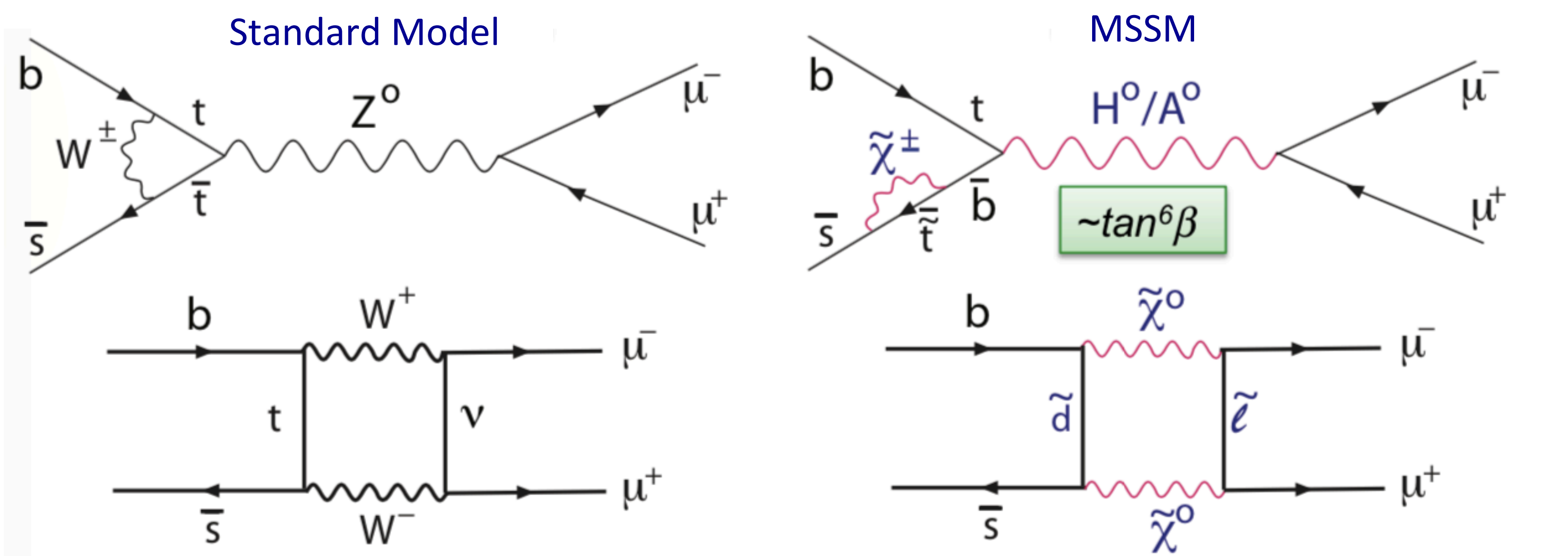
- These results are twice as precise as previous LHCb results.
- No CP violation. $A_D \equiv (R_D^+ - R_D^-)/(R_D^+ + R_D^-) = (-0.1 \pm 8.1 \pm 4.2) \times 10^{-3}$

Rare decays

$B_s \to \mu\mu$ decays

The decay $B_s \to \mu\mu$ is ultra-rare in the SM and very sensitive to NP contributions.

- SM branching fraction calculated with small uncertainty: $(3.65 \pm 0.23)\times10^{-9}$.
- BSM theories (esp. additional Higgs bosons) predict enhanced rates. PRL 112 (2014) 101801

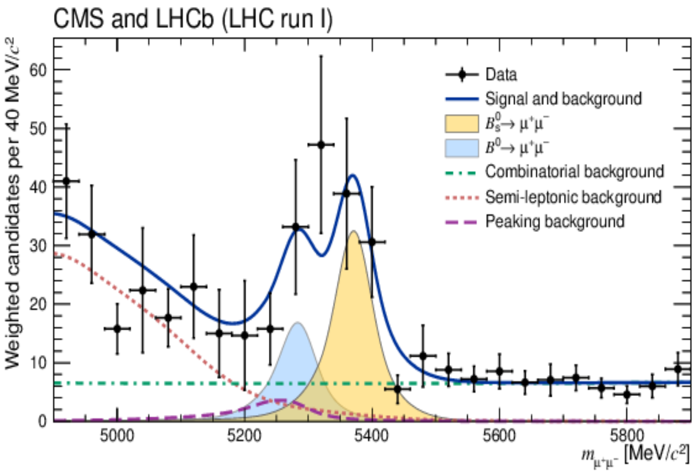


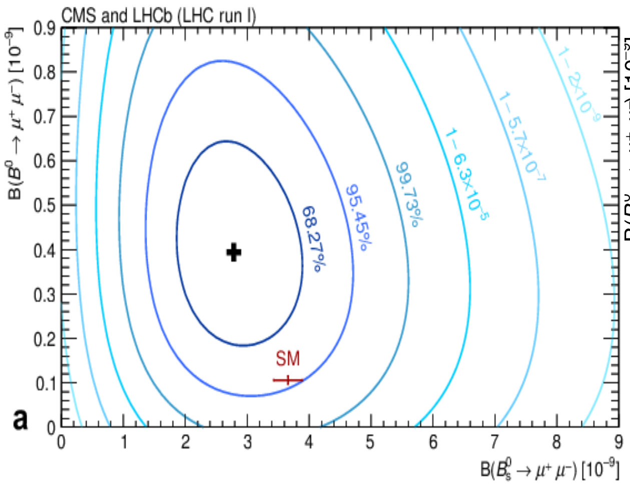
- LHCb found the first evidence of the decay in Run-1. PRL 110 (2013) 021801
- A combined CMS and LHCb analysis obtained a 5σ observation. Nature 522 (2015) 68

$B_s \to \mu\mu$ decays

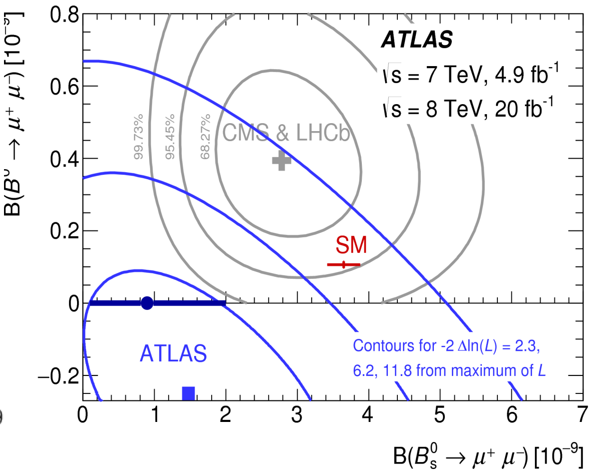
Run-1 combined LHCb + CMS $B_s^0 \to \mu\mu$ and $B^0 \to \mu\mu$ analysis and ATLAS analysis:

Nature 522 (2015) 68





Eur. Phys. J C76 (2016) 513



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(2.8\,^{+0.7}_{-0.6}\right) \times 10^{-9}$$ (6.2σ)

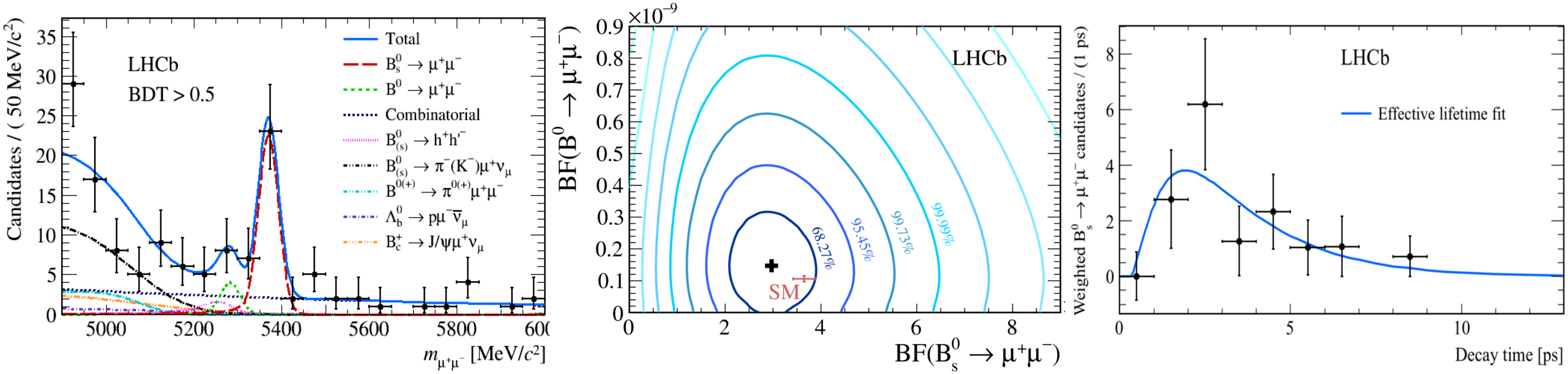
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \left(3.9\,^{+1.6}_{-1.4}\right) \times 10^{-10}$$ (3.0σ)

No evidence for either mode in ATLAS measurement.

- First observation of $B_s^0 \to \mu\mu$ and evidence of $B^0 \to \mu\mu$.
- Compatible with the SM at 1.2σ (2.2σ).

$B_s \to \mu\mu$ decays

LHCb Run-1 + Run-2 update on $B_s^0 \to \mu\mu$ and $B^0 \to \mu\mu$ analysis:



$N_{Bs} = 62 \pm 6$, $N_{B0} = 6.7 \pm 0.6$

PRL 118 (2017) 191801

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9} \quad (7.8\sigma)$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10}$$

- First observation of $B_s^0 \to \mu\mu$ from a single experiment.
- Compatible with the SM, tighten constraints on NP contributions.
- Effective lifetime fit – proof of principle. $\tau(B_s^0 \to \mu^+\mu^-) = 2.04 \pm 0.44 \pm 0.05$ ps

Tests of Lepton Flavour Universality

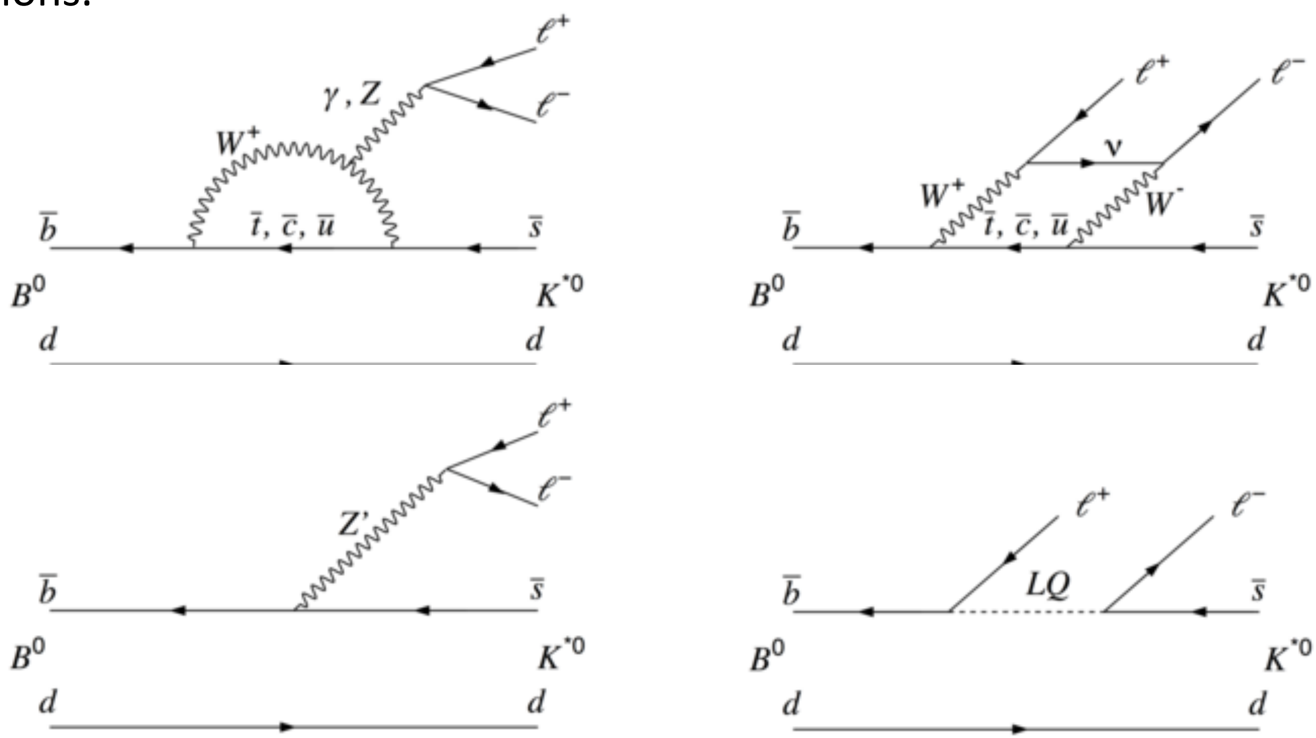
Lepton flavour universality (LFU)

In the SM, the electroweak couplings of leptons to gauge bosons are independent of their flavour.

- FCNC processes (electroweak loop diagrams such as $b \to s l^+ l^-$) are ideal to test LFU.
- NP particles (Z’, LQ, …) with unequal couplings to leptons can alter rates or angular distributions.

SM:

NP?



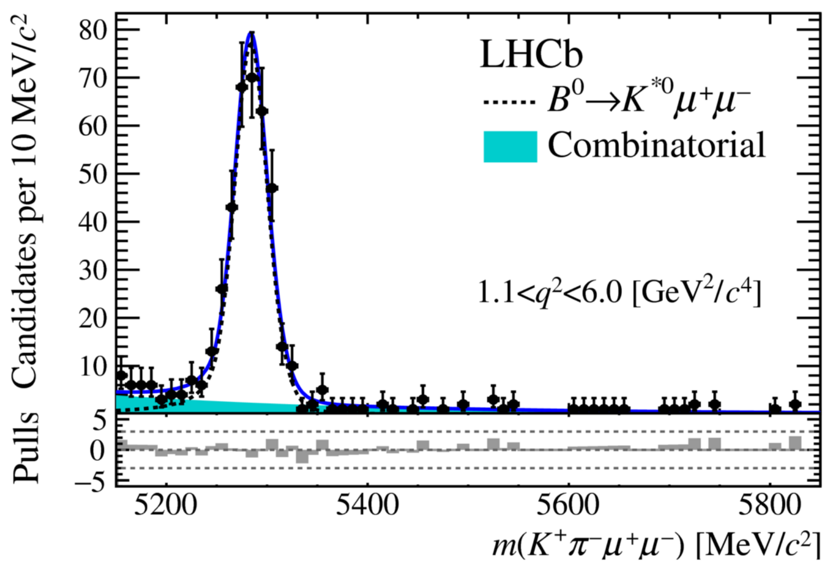
LFU tests in $b \to s l^+ l^-$ transitions

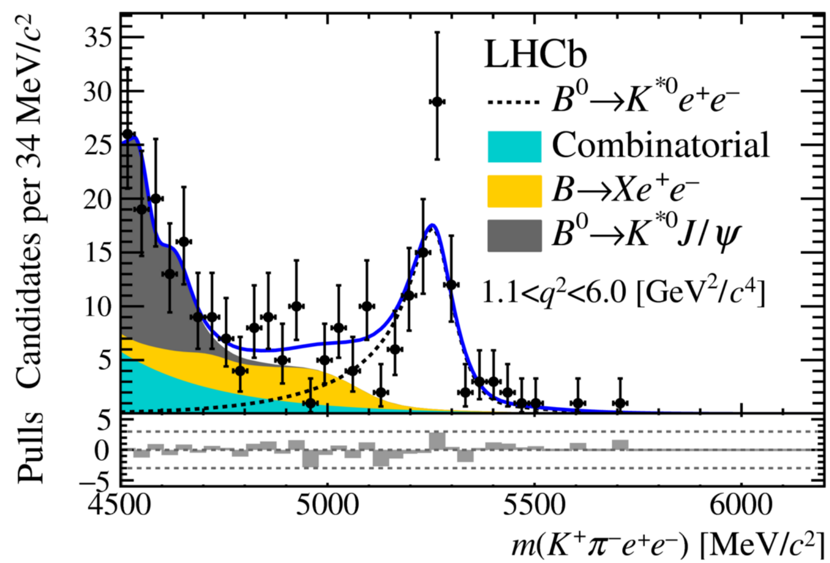
Measure ratios of branching fractions to e/μ for these EW loop transitions:

- Precise SM theoretical predictions ($O(10^{-3})$ R_K uncertainty).
- Hadronic form-factor uncertainties cancel in ratios.
- Common selection, double ratios reduce experimental systematics.

$$R_K \equiv \frac{BR(B^+ \to K^+ \mu^+ \mu^-)}{BR(B^+ \to K^+ e^+ e^-)}$$

$$R_{K^*} \equiv \frac{BR(B^0 \to K^* \mu^+ \mu^-)}{BR(B^0 \to K^* e^+ e^-)}$$





The experimental challenge is electron reconstruction:

JHEP 08 (2017) 055

- Brehmsstrahlung, lower trigger efficiencies.

LFU tests in $b \to s l^+ l^-$ transitions

Measurements of R_K and R_{K*} in bins of $q^2 = m^2(l^+l^-)$:

$$R_K \equiv \frac{BR(B^+ \to K^+ \mu^+ \mu^-)}{BR(B^+ \to K^+ e^+ e^-)}$$

$$R_{K^*} \equiv \frac{BR(B^0 \to K^* \mu^+ \mu^-)}{BR(B^0 \to K^* e^+ e^-)}$$

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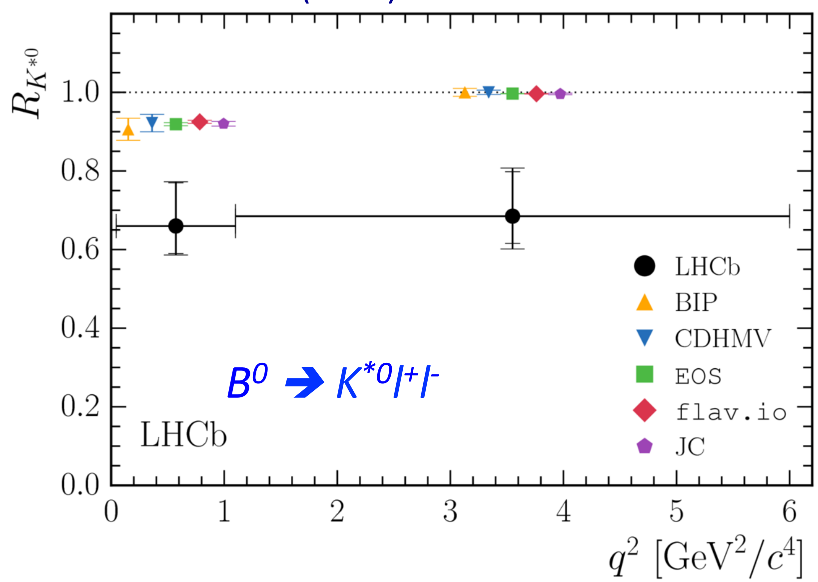
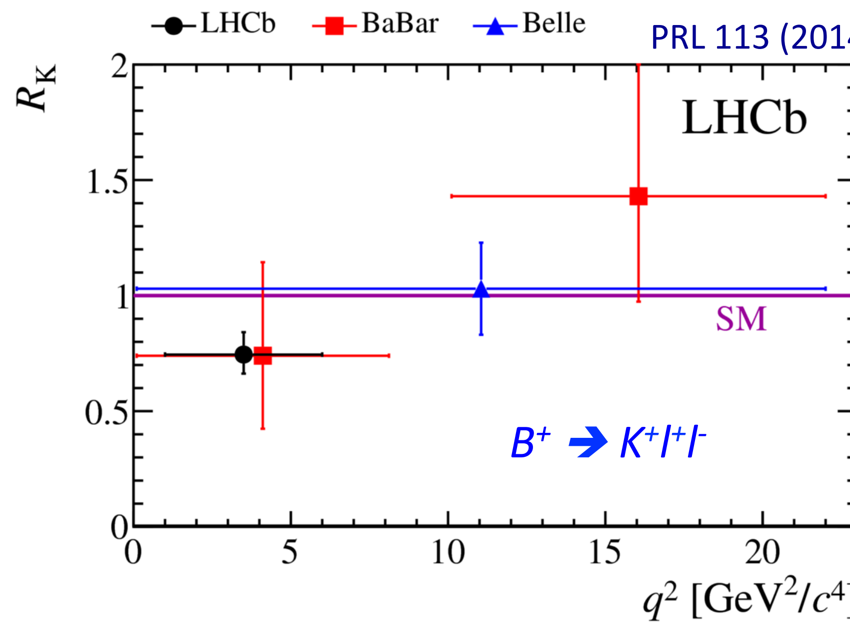


PRL 113 (2014) 151601



	low- q^2	central- q^2
$R_{K^{*0}}$	$0.66\,^{+\,0.11}_{-\,0.07} \pm 0.03$	$0.69\,^{+\,0.11}_{-\,0.07} \pm 0.05$

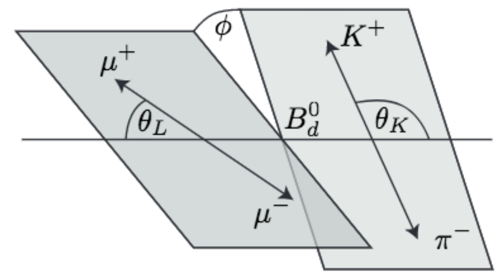
$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

- Most precise results to date.
- Below the SM predictions at 2.1-2.3σ, 2.4-2.5σ and 2.6σ.

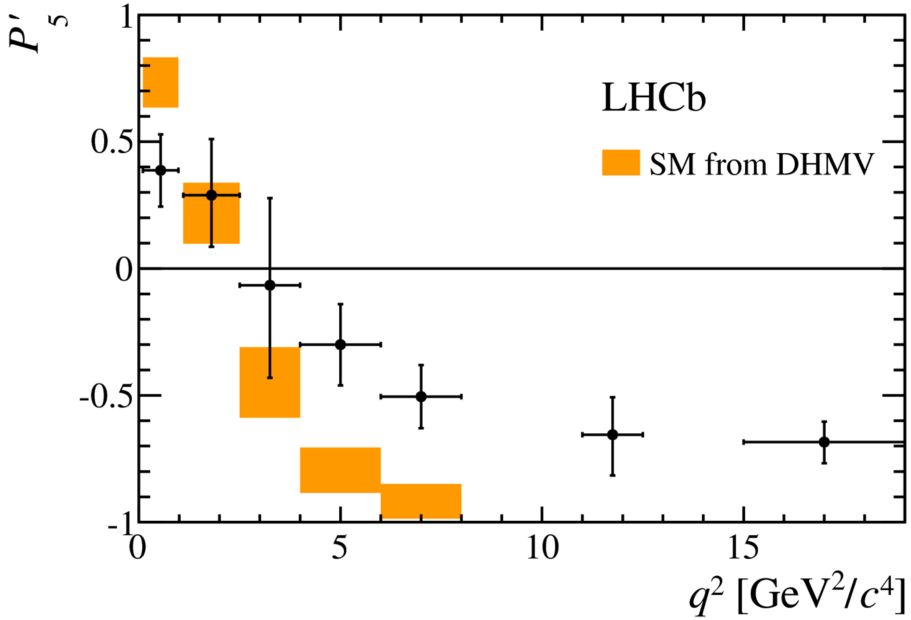
Other $b \rightarrow sl^+l^-$ anomalies

Measure angular observables of $B^0 \rightarrow K^{*0}(K^+\pi^-)\mu^+\mu^-$ decays in bins of $q^2 = m^2(l^+l^-)$:

- Three decay angles, full angular analysis.
- Angular distribution described by 8 coefficients.
- Optimised observables with reduced theoretical uncertainties.



JHEP 02 (2016) 104



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

$$P'_5 = S_5/\sqrt{F_L(1-F_L)}$$

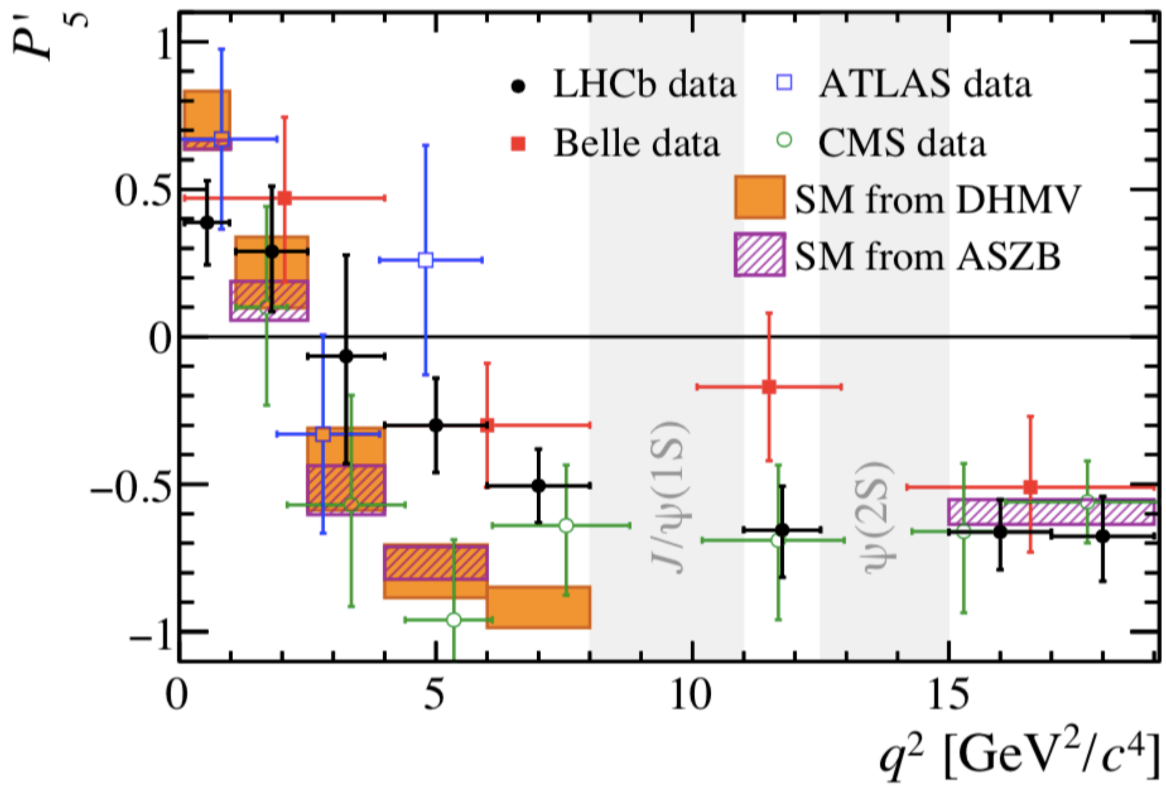
- Observables consistent with SM, except P'_5 which differs by 3.4σ in two bins.

Other $b \to sl^+l^-$ anomalies

Measure angular observables of $B^0 \to K^{*0}(K^+\pi^-)\mu^+\mu^-$ decays in bins of $q^2 = m^2(l^+l^-)$:

- CMS, ATLAS and Belle also measure P'_5.

$$P'_5 = S_5/\sqrt{F_L(1-F_L)}$$



LHCb: JHEP 02 (2016) 104

CMS: arXiv 1710.02846

ATLAS-CONF-2017-023

Belle: PRL 118 (2017) 111801

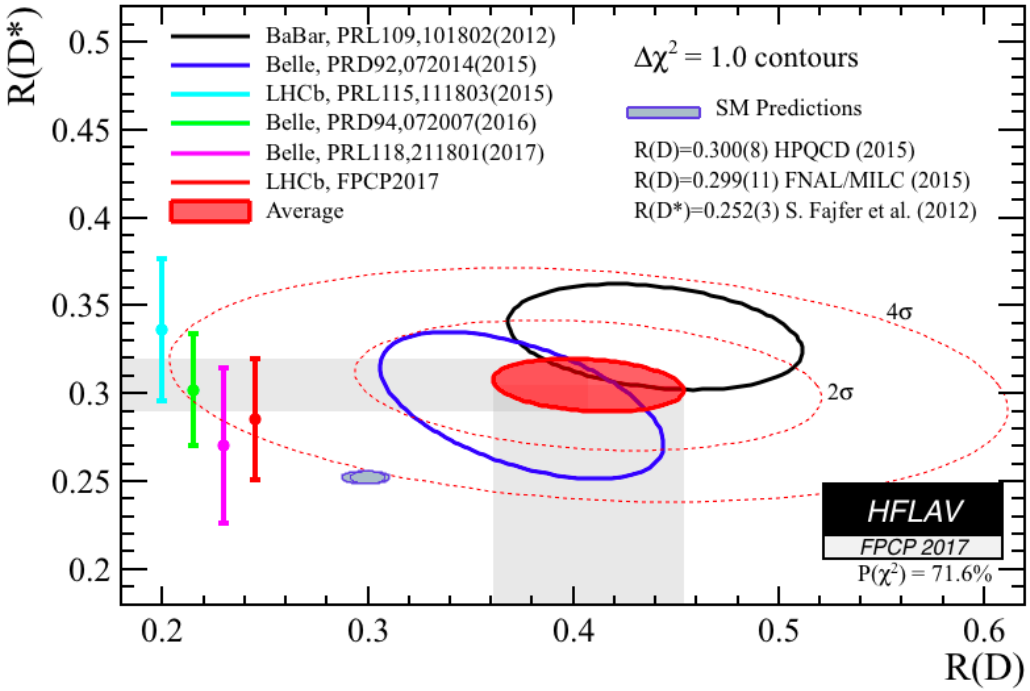
- The shift could be caused by a contribution from a new vector particle or by an unexpectedly large hadronic effect.

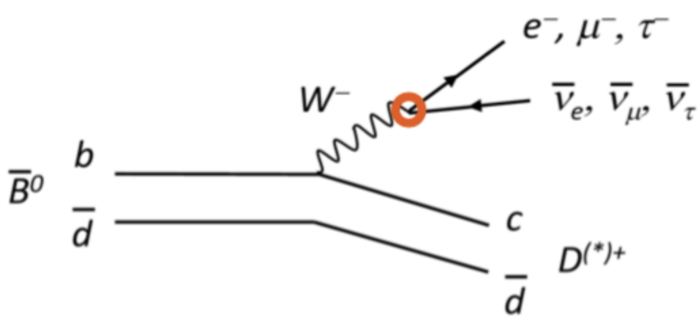
LFU tests in semileptonic *b* decays

Measure ratios of branching fractions R(D$^{(*)}$):

$$R(D^{(*)}) \equiv \frac{BR(\overline{B}^0 \to D^{(*)+}\tau^-\overline{\nu}_\tau)}{BR(\overline{B}^0 \to D^{(*)+}\mu^-\overline{\nu}_\mu)}$$

- Tree-level transitions with large BR, precise predictions.
- Experimentally challenging: multiple neutrinos from W and τ decays.





LHCb: $\tau^+ \to \mu^+\nu\nu$

PRL 115 (2015) 111803

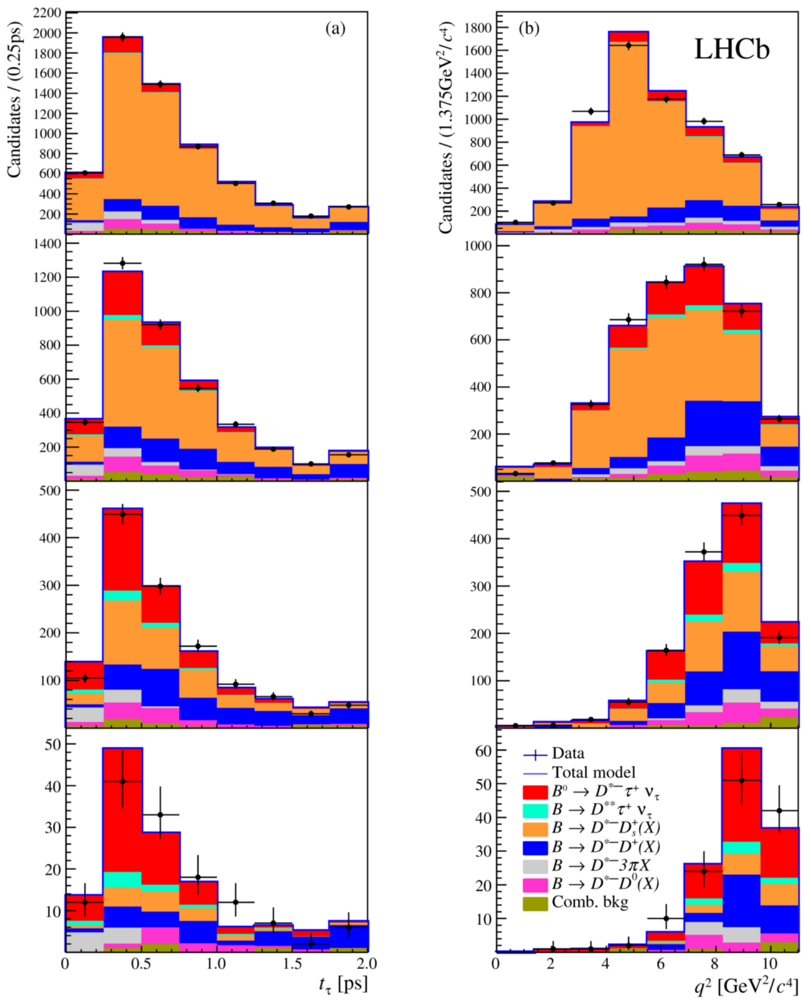
- Enhanced in models with extended Higgs, LQ or extended gauge sector.
- Long-standing discrepancy with the SM at 4σ (Belle, BaBar, LHCb).

R(D*) from three-prong τ decays

Measure ratios of branching fractions R(D$^{(*)}$):

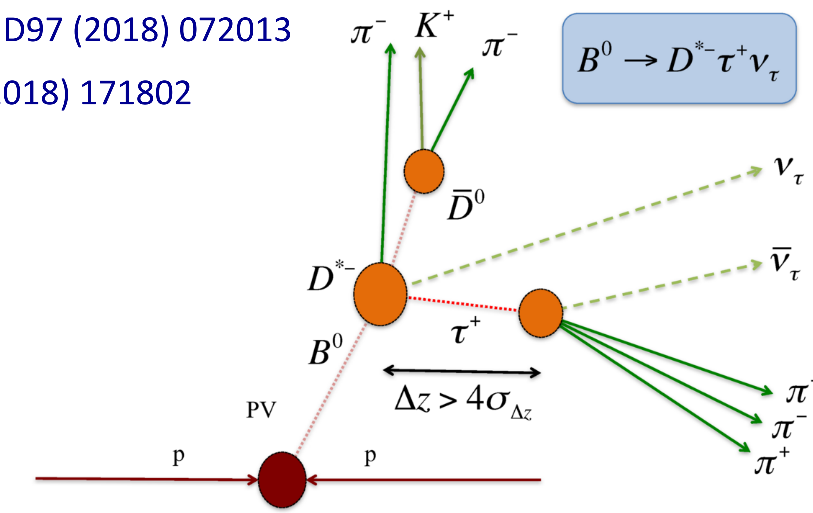
- LHCb measurement using $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\nu$ decays.

$$R(D^{(*)}) \equiv \frac{\mathrm{BR}\,(\overline{B}^0 \to D^{(*)+}\tau^-\overline{\nu}_\tau)}{\mathrm{BR}\,(\overline{B}^0 \to D^{(*)+}\mu^-\overline{\nu}_\mu)}$$



Phys. Rev. D97 (2018) 072013

PRL 120 (2018) 171802



- Large background from $B^0 \to D^{*+}\pi^+\pi^-\pi^+X$ decays, suppressed using τ decay length.
- 3D binned fit in q_2, t_τ and BDT output.

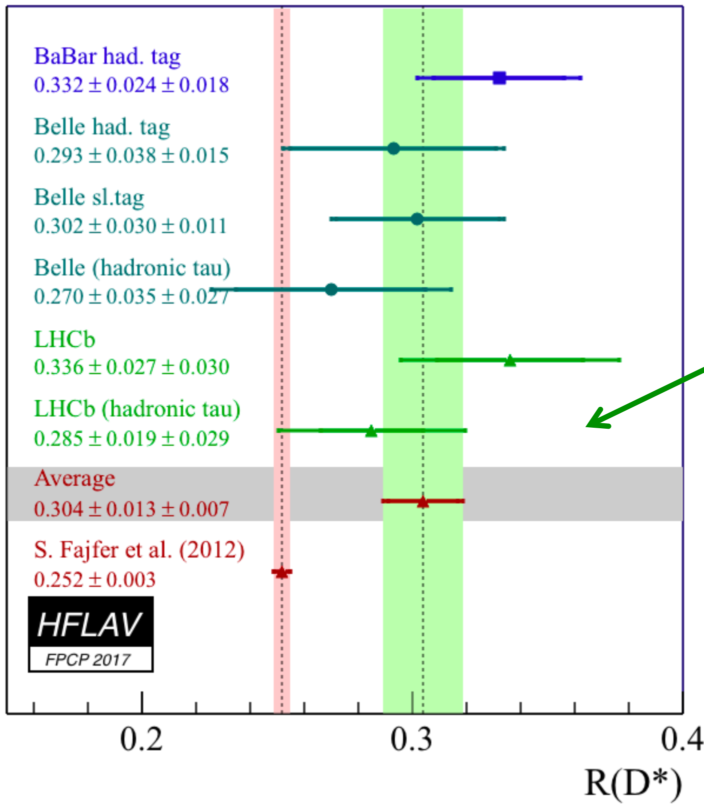
$N_{sig} = 1296 \pm 86$

R(D*) from three-prong τ decays

Measure ratios of branching fractions $R(D^{(*)})$:

$$R(D^{(*)}) \equiv \frac{BR(\overline{B}^0 \to D^{(*)+} \tau^- \overline{\nu}_\tau)}{BR(\overline{B}^0 \to D^{(*)+} \mu^- \overline{\nu}_\mu)}$$

- LHCb measurement using $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\nu$ decays.



$$\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau) = [1.42 \pm 0.094(\text{stat}) \pm 0.129(\text{syst}) \pm 0.054(\text{ext})] \times 10^{-2}$$

$$\mathcal{R}(D^{*-}) = 0.291 \pm 0.019(\text{stat}) \pm 0.026(\text{syst}) \pm 0.013(\text{ext})$$

Phys. Rev. D 97 (2018) 072013,
Phys. Rev. Lett. 120 (2018) 171802

- First measurement with three-prong decays, novel technique can be applied to other semitauonic analyses.
- Latest result compatible with the SM at 1σ.
- Combined R(D) and R(D*) at 4.1σ from SM.

Conclusions

- Flavour physics plays a key role in searching for New Physics.

- The experimental progress on precision measurements of flavour observables provides stringent tests of the SM and challenges to BSM theories.
  - CKM triangle and CP violation measured with improved precision − agree with the SM so far.
  - Rare $B_{(s)}^0 \to \mu\mu$ decays tighten the constraints on BSM models.
  - Several anomalies in Lepton Flavour Universality tests diverge from the SM.

- Run-2 data are being analysed and will help confirm or refute some of these hints.
- Upgrades ahead + Belle II.