Flavour physics as a tool for new physics searches

Status and long-term prospects

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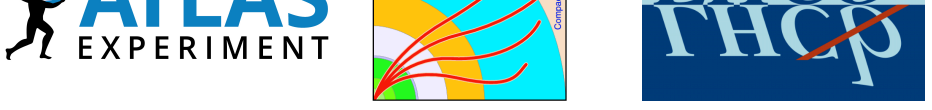
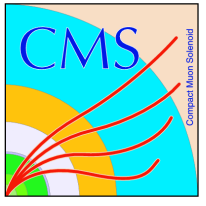
[WG4, with Alex Cerri, Vava Gligorov*, Sandra Malvezzi]

on behalf of





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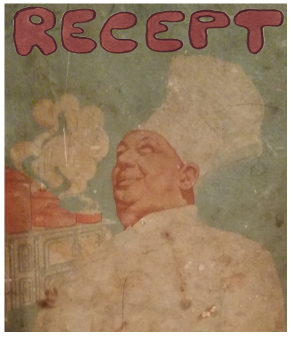

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Flavour physics programme in a nutshell

- Classic broad-range measurements
  - CKM physics, search for very rare decays
- Measurements in specific sectors where anomalies are emerging in recent years
  - Lepton-flavour universality in $b \to s\ell^+\ell^-$ transitions, and related $b \to s\ell^+\ell^-$ picture of decay rates
  - Lepton-flavour universality in semileptonic b-hadron decays
- Spectroscopy
  - While primarily looking for BSM physics, the LHC is also a unique laboratory to better understand QCD in the low-energy regime

Classic programme

CKM physics and rare decays

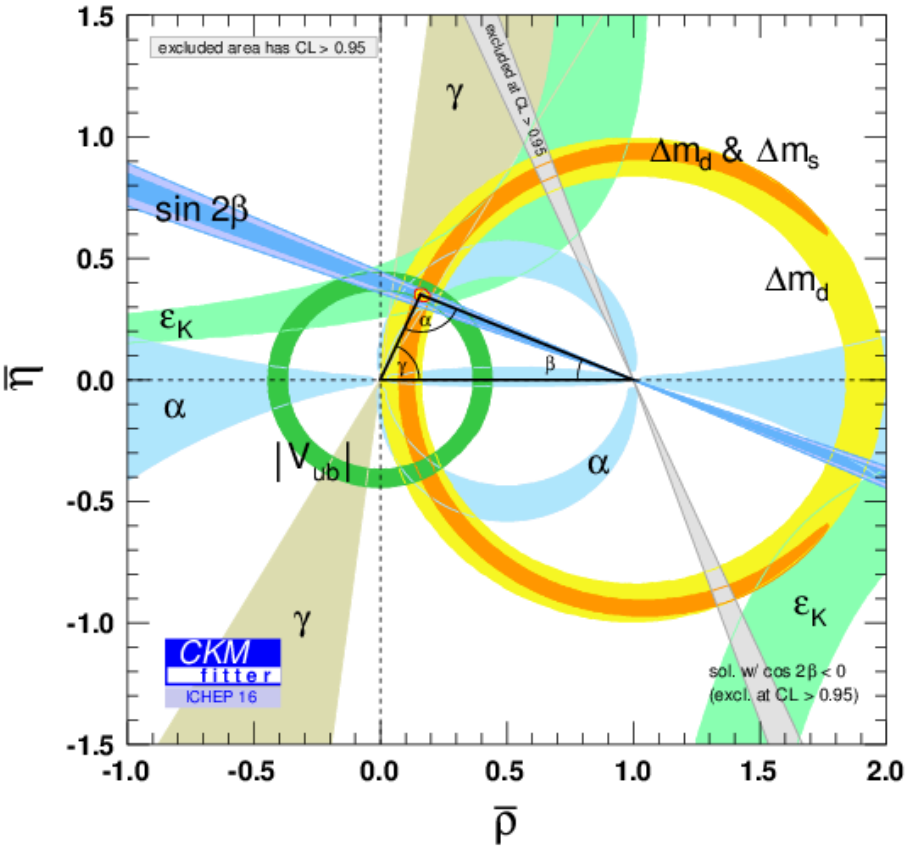
- Look for inconsistencies in global CKM fits
  - Measure *CP* violation in the interference between B^0 and B_s mixing and decay
    - Phases ϕ_s and $\sin 2\beta$ and related measurements
  - Measure the *CP*-violating angles γ and α of the UT
  - Measure UT sides Δm_d and Δm_s, $|V_{ub}|/|V_{cb}|$
  - Search for *CP* violation in charm mixing and decay, and measure precisely D^0-meson mixing parameters
- Search for (or precisely measure) rare and lepton-flavour violating decays
  - $K_S \to \mu\mu$, $B^0 \to \mu\mu$, $B_s \to \mu\mu$, ...
  - $\tau \to 3\mu$, $D \to e\mu$, $B \to e\mu$, ...

In this talk

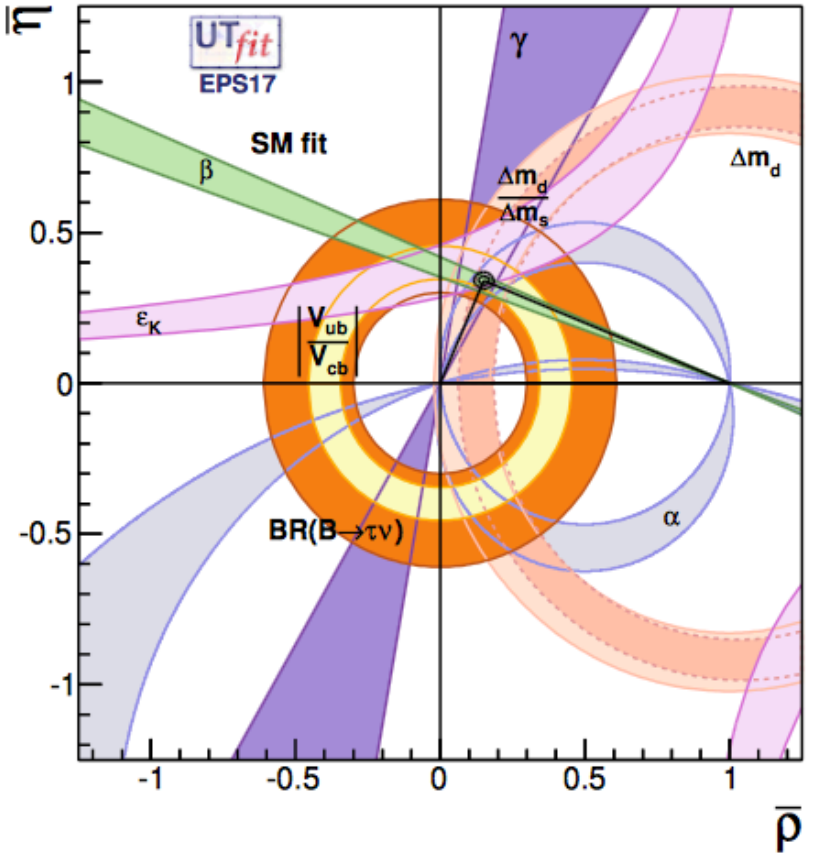
In the backup

Where we are with global UT fits

http://ckmfitter.in2p3.fr

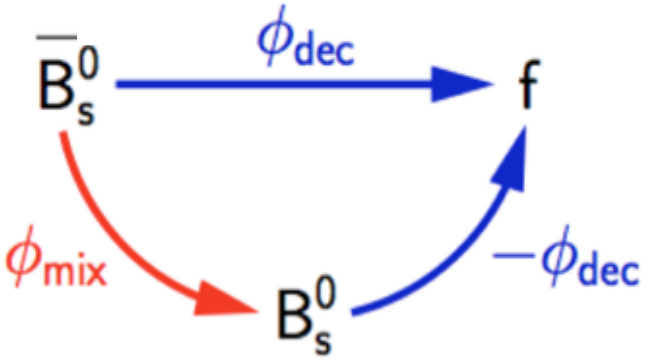


http://www.utfit.org

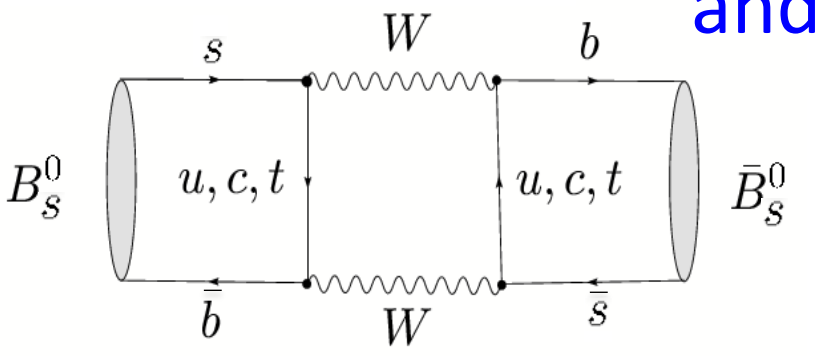


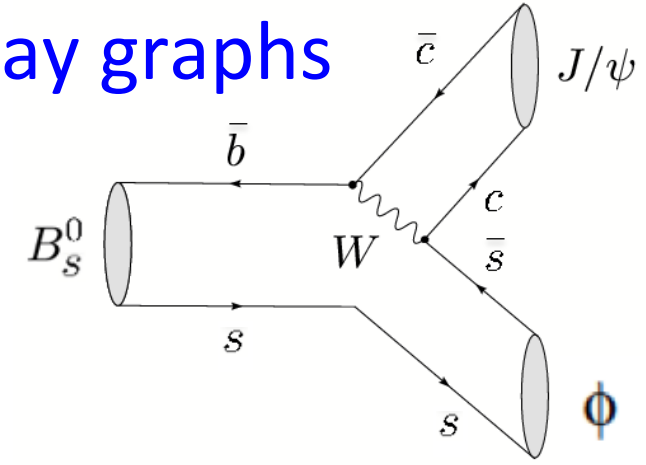
- Don't forget: relevant inputs from LQCD, flavour theory and constant dedication from the HFLAV group (http://www.slac.stanford.edu/xorg/hflav/)
- In the presence of relevant new physics effects, the various contours would not cross each other in a single point
- Certainly that's a great success of the Standard Model CKM picture, but there is still room for new physics at the 10%-15% level

ϕ_s from $b \to c\bar{c}s$ transitions



- Golden mode $B_s \to J/\psi\phi$ proceeds (mostly) via a $b \to c\bar{c}s$ tree diagram
- Interference between B_s mixing and decay graphs

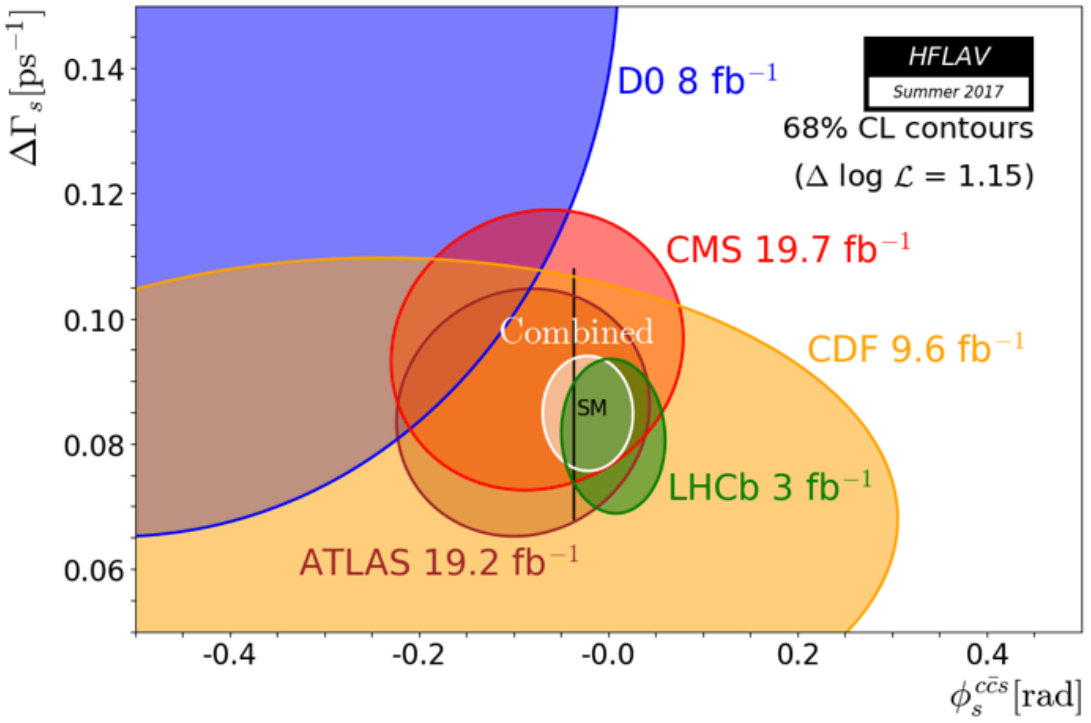




- Measures the phase-difference ϕ_s between the two diagrams, precisely predicted from global CKM fits in the SM to be $\phi_s = -2\lambda^2\eta = -37.4 \pm 0.7$ mrad → can be altered by new physics
  - But also affected by small pollution of sub-leading SM amplitudes that must be taken under control via subsidiary measurements

ϕ_s , $\Delta\Gamma_s$ and $\Delta\Gamma_d$

Parallel WG4 talks by
Francesca Dordei
Pavel Reznicek
Subir Sarkar



- ϕ_s precision mostly driven by LHCb, but ATLAS and CMS also contribute significantly to the global endeavour
- Latest HFLAV world average
  - $\phi_s = -21 \pm 31$ mrad
- Still compatible with the SM at the present level of precision

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	$+0.085 \pm 0.006$	

[a] $m(K^+K^-) > 1.05$ GeV/c^2.

See HFLAV page for the list of references
http://www.slac.stanford.edu/xorg/hflav/

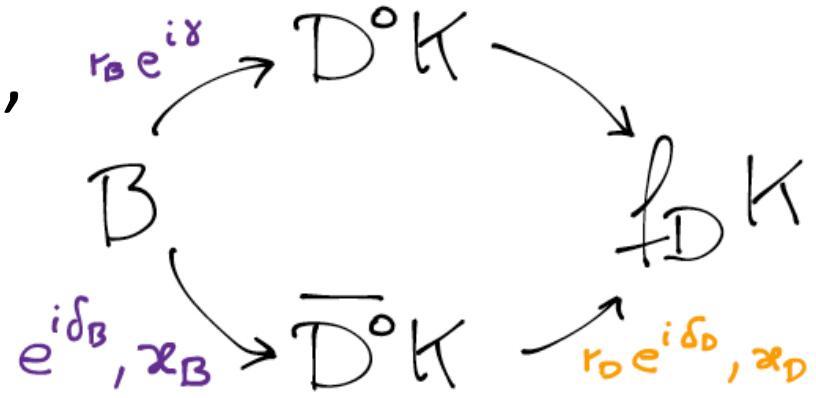
- Also most precise measurement of $\Delta\Gamma_d/\Gamma_d$ by ATLAS, by comparing decay-time distributions of $B^0 \to J/\psi K_S$ and $B^0 \to J/\psi K^{*0}$ decays

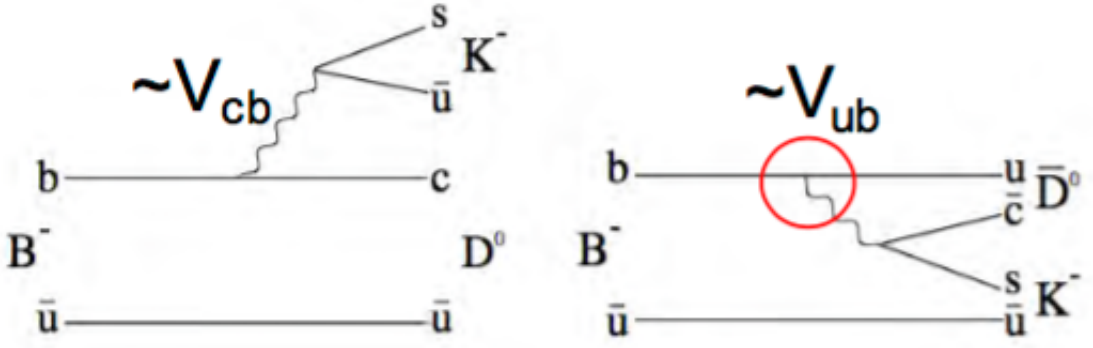
$$\Delta\Gamma_d/\Gamma_d = (-0.1 \pm 1.1\ (\text{stat.}) \pm 0.9\ (\text{syst.})) \times 10^{-2}$$

JHEP 06 (2016) 081

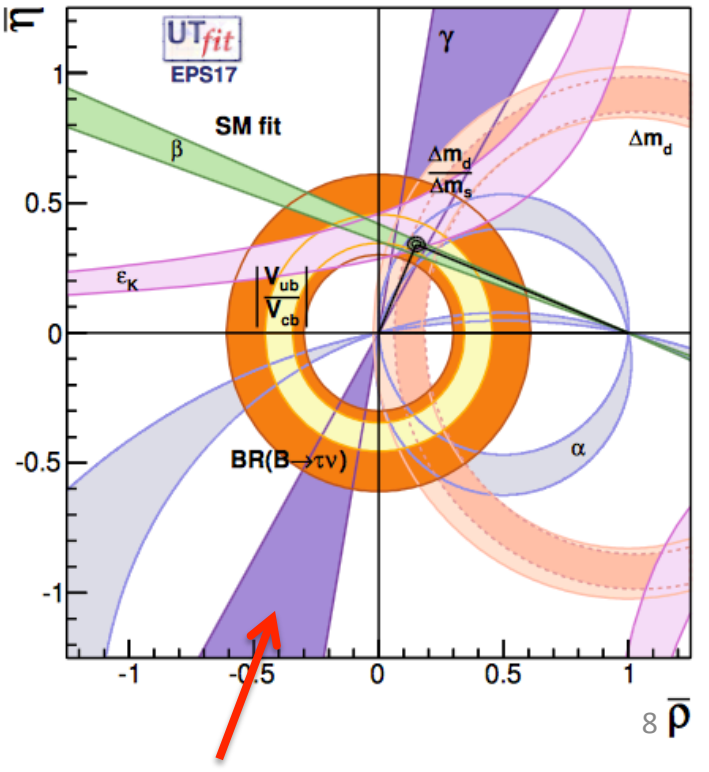
Measurement of γ

- γ is the least known angle of the UT, although not for too long yet, measured via the interference between $b \to u$ and $b \to c$ tree-level transitions





- Simple and clean theoretical interpretation, but statistically very challenging



LHCb combination for γ

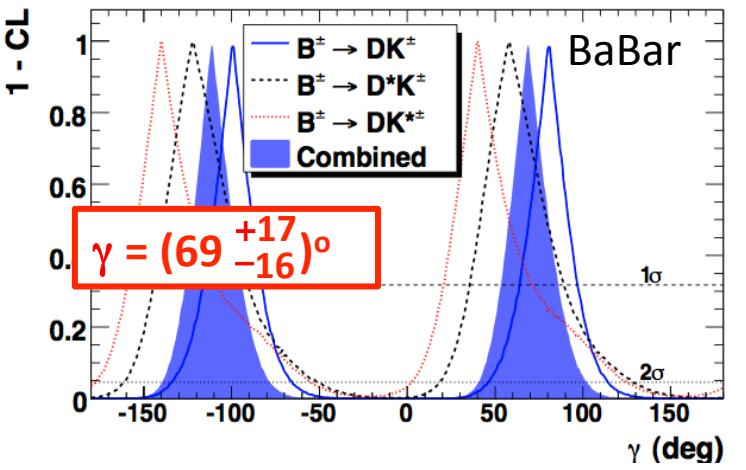
- A plethora of independent measurements exploiting different methods and decays
- Recent additions to the LHCb combination

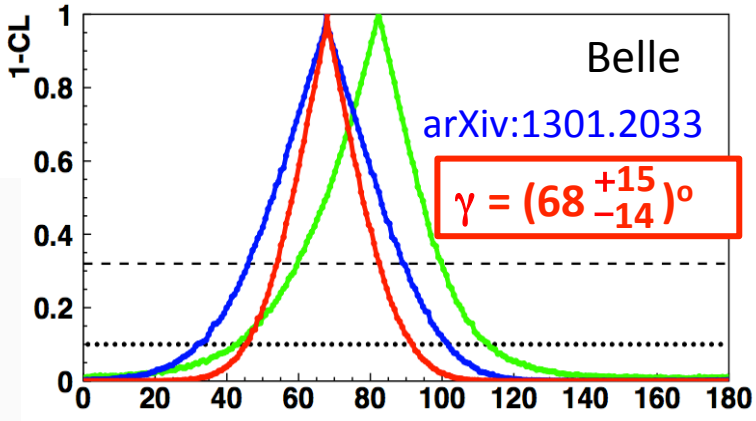
- $B^{\pm} \to D^0 K^{*\pm}$ ADS/GLW [LHCb-CONF-2016-014] NEW
- $B^{\pm} \to D^{*0} K^{*\pm}$ GLW [LHCb-PAPER-2017-021] NEW
- $B_s^0 \to D_s^{\mp} K^{\pm}$ TD [LHCb-CONF-2016-015] $1\ \text{fb}^{-1} \to 3\ \text{fb}^{-1}$
- $B^{\pm} \to D^0 K^{\pm}$ GLW [LHCb-PAPER-2017-021] $3\ \text{fb}^{-1} \to 5\ \text{fb}^{-1}$

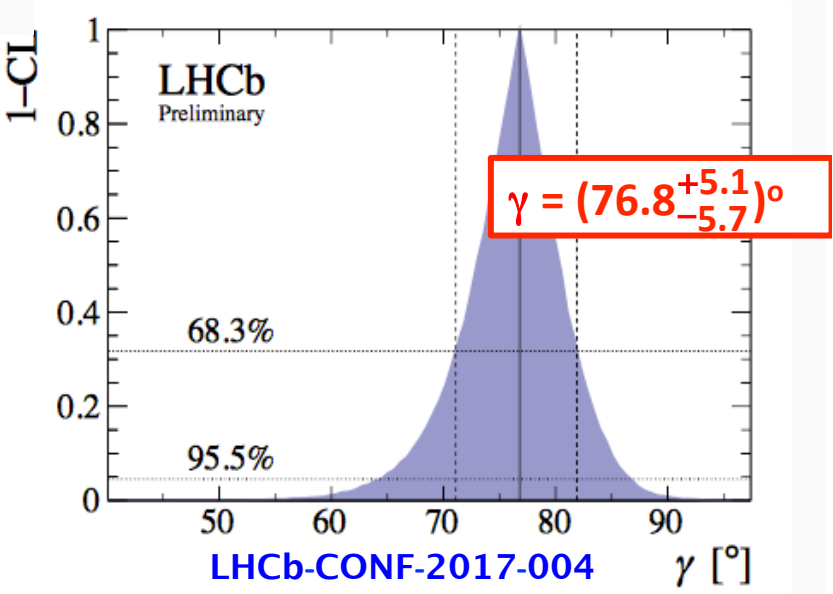
- Significantly more precise than previous results from the *B*-factories and undergoing continuous improvements

Parallel WG4 talk by Francesca

Phys. Rev. **D87** (2013) 052015







Δm_d and Δm_s

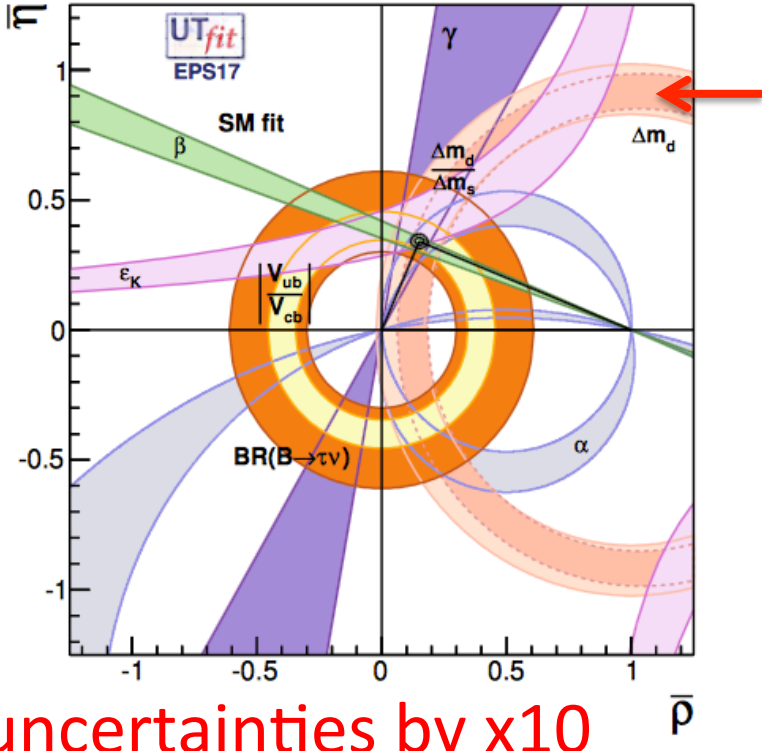
- Experimental precision has reached a remarkable level at the per mille level, dominated by LHCb
  - $\Delta m_d = 0.5065 \pm 0.0019\ ps^{-1}$
  - $\Delta m_s = 17.757 \pm 0.021\ ps^{-1}$
- However, the interpretation requires inputs from LQCD

$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_W^2\, \eta_c S(x_t)\, A^2\lambda^6\, [(1-\bar{\rho})^2+\bar{\eta}^2]\, m_{B_d} f_{B_d}^2 \hat{B}_{B_d}$$

~7%

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d} f_{B_d}^2 \hat{B}_{B_d}}{m_{B_s} f_{B_s}^2 \hat{B}_{B_s}} \left(\frac{\lambda}{1-\frac{\lambda^2}{2}}\right)^2 [(1-\bar{\rho})^2+\bar{\eta}^2]$$

~4%

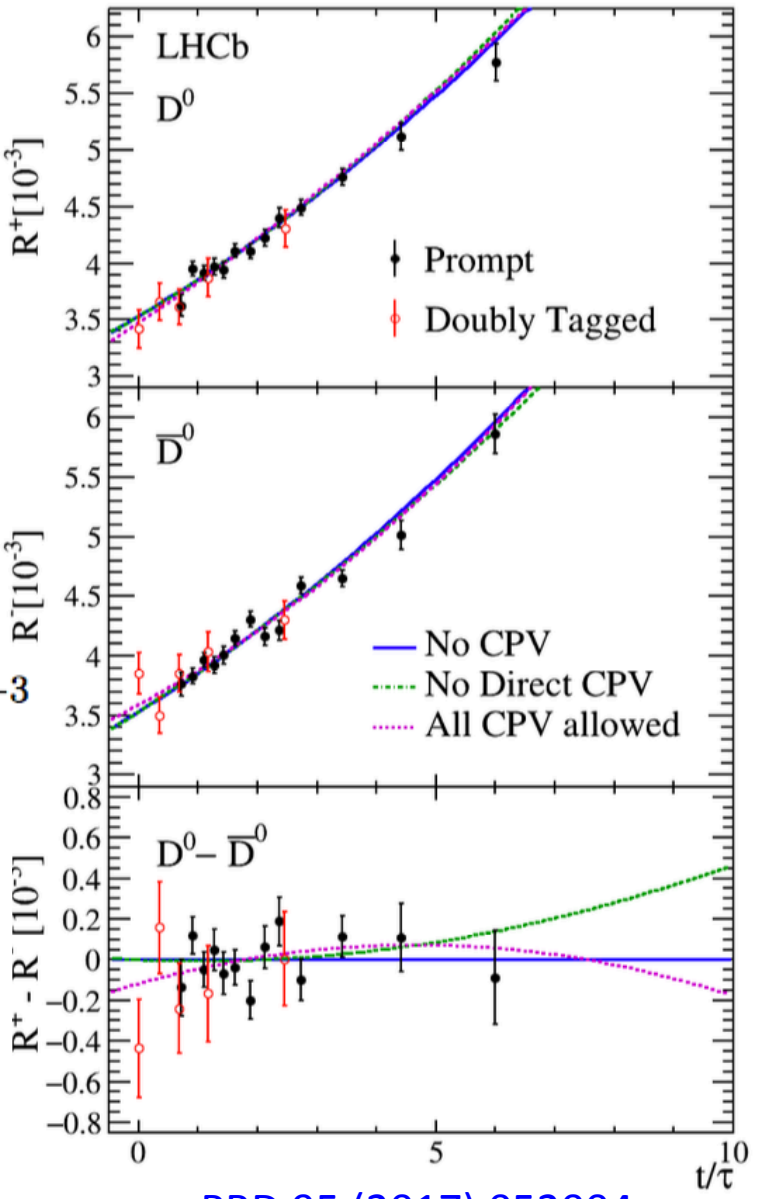


- The quest for precision with these constraints is now on LQCD
  - Need to sustain efforts from the LQCD community to reduce the theoretical uncertainties by x10

Mixing and *CP* violation in charm

- D^0-$\bar{D}^0$ mixing established by LHCb with overwhelming sensitivity measuring mainly time-dependent ratio of WS to RS $D^0 \to K\pi$ decays
- "Large" mixing encourages searches for *CP* violation
  - Both direct and indirect *CP* violation searches have been performed with unprecedented precision

$$R(t) = \frac{N(D^0 \to K^+\pi^-)}{N(D^0 \to K^-\pi^+)}$$



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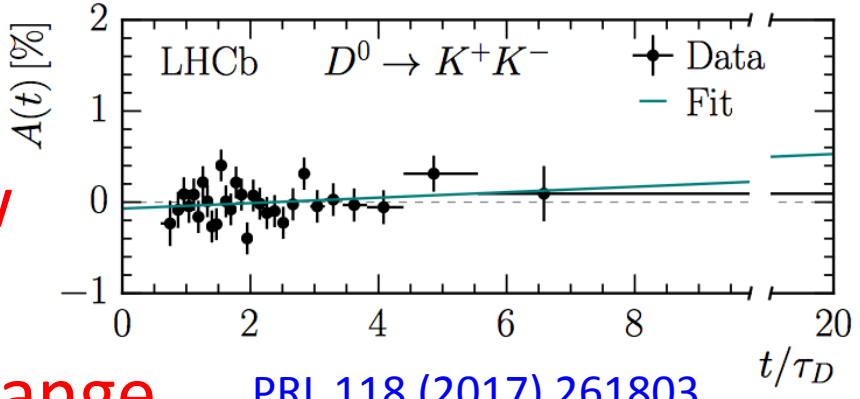
$$A_\Gamma \equiv \frac{\Gamma(D^0 \to KK) - \Gamma(\bar{D}^0 \to KK)}{\Gamma(D^0 \to KK) + \Gamma(\bar{D}^0 \to KK)} = (-0.30 \pm 0.32 \pm 0.10) \times 10^{-3}$$

- No sign of *CP* violation yet, but now entering the interesting range



PRL 118 (2017) 261803

Parallel WG4 talk by Francesca

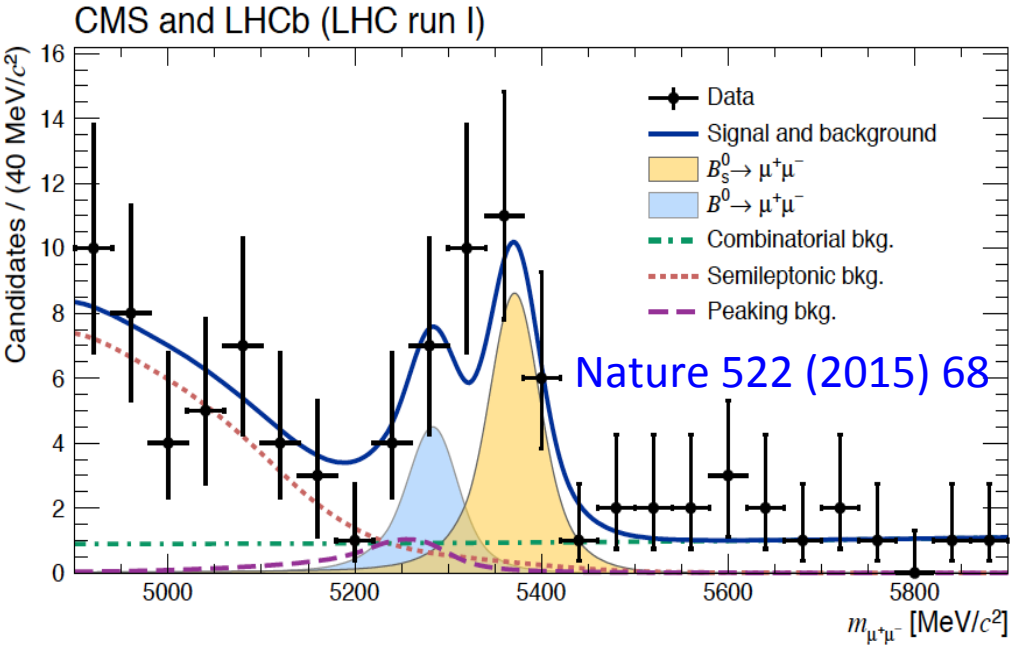
$B^0 \to \mu^+\mu^-$ and $B_s \to \mu^+\mu^-$

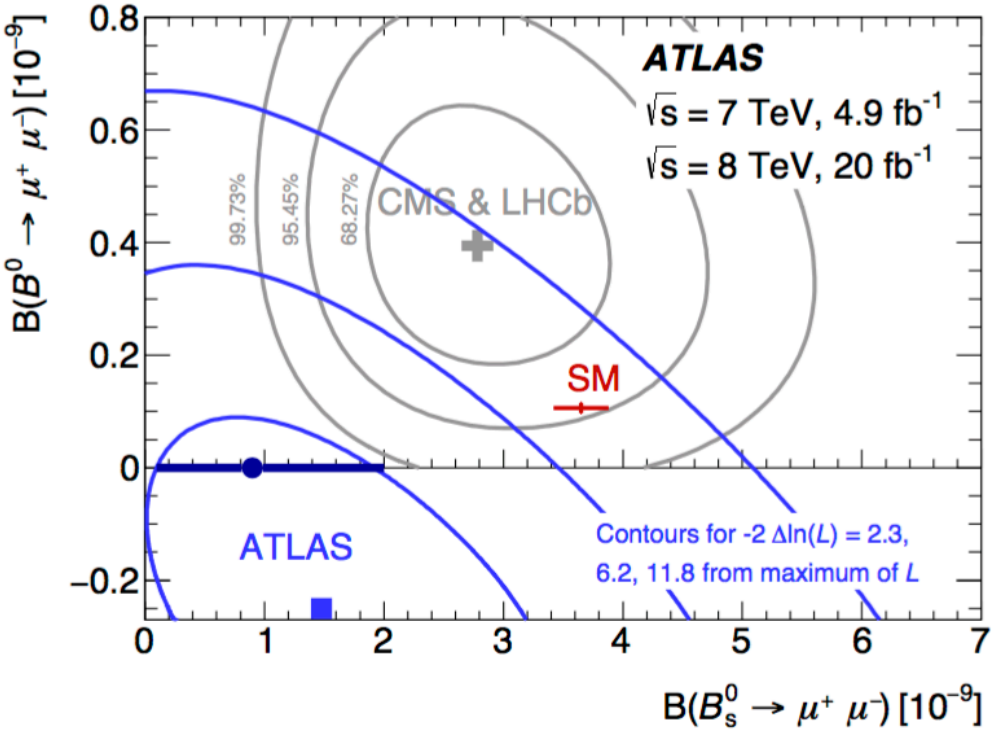
- CMS and LHCb have performed a combined fit to their full Run-1 data sets

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

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

- $B_s \to \mu\mu$ 6.2σ significance was first observation
  - Compatibility with the SM at 1.2σ
- Excess of events at the 3σ level for $B^0 \to \mu\mu$
  - Compatible with SM at 2.2σ
- More recently, also ATLAS published a measurement with Run-1 data





Parallel WG4 talks by Paula Alvarez Cartelle, Pavel, Subir

Update on $B \to \mu\mu$ by LHCb with Run-2 data

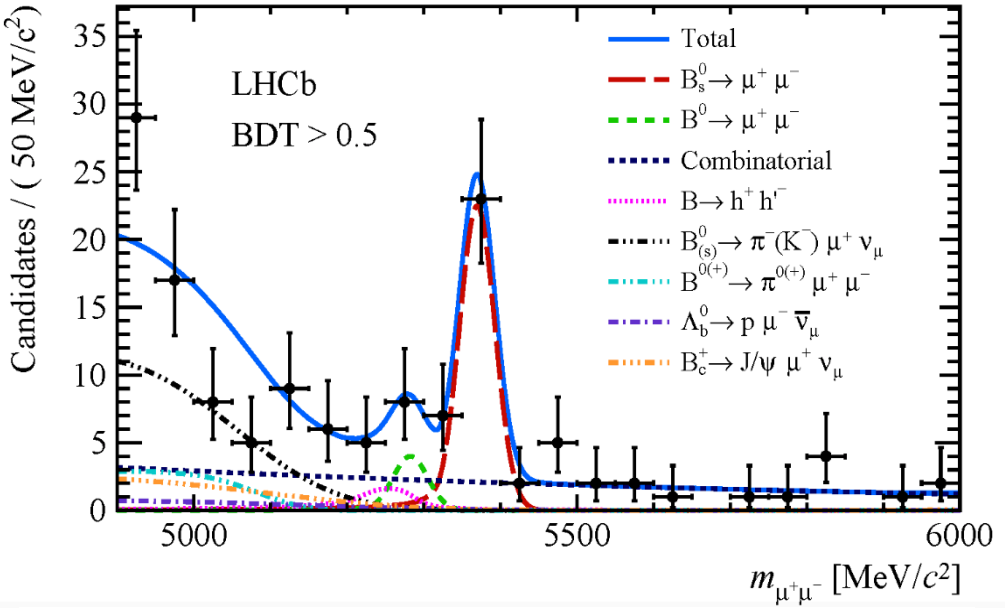
Parallel WG4 talk by Paula

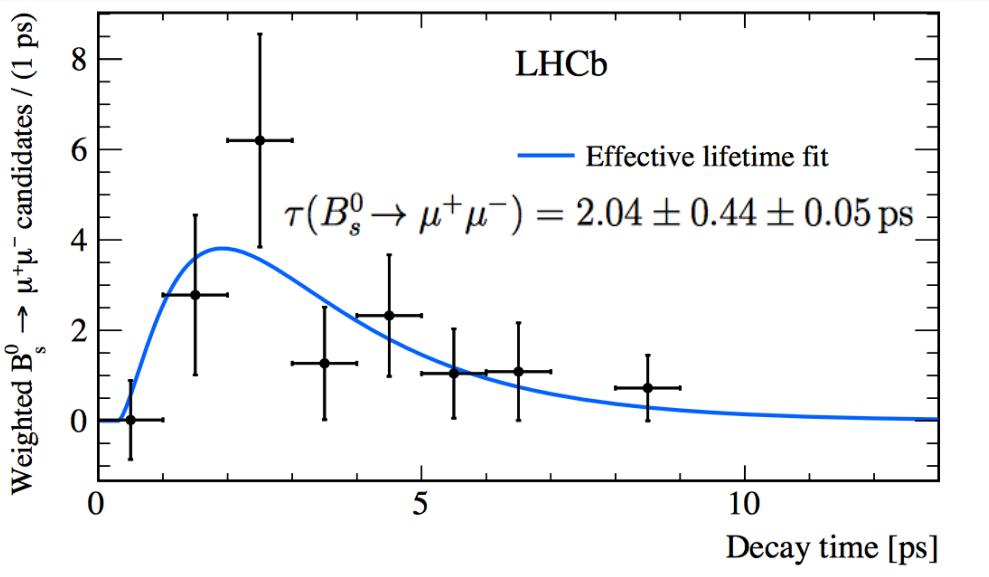
- New measurement from LHCb using Run-2 data has led this year to the first observation of the $B_s \to \mu\mu$ decay from a single experiment

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

- Moreover, it starts to be possible to measure other properties, such as the effective lifetime, that will be useful for discriminating between NP models
  - Experimental precision not yet in the interesting range, but important proof of concept

Phys. Rev. Lett. 118, 191801 (2017)





Flavour anomalies

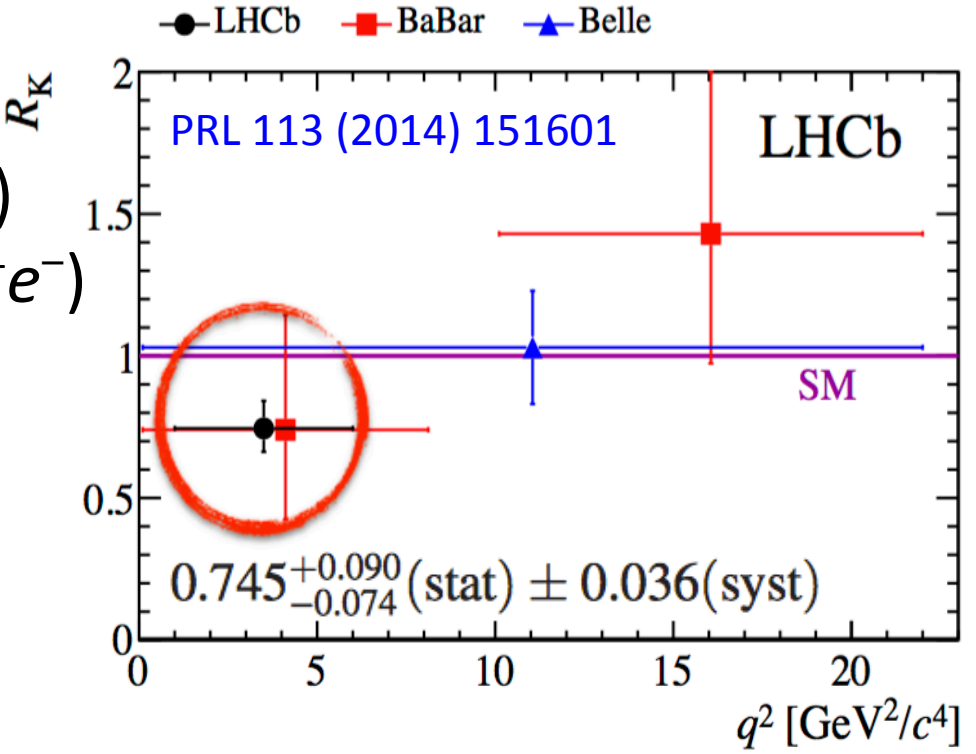
LFU tests in $b \to s\ell^+\ell^-$ transitions

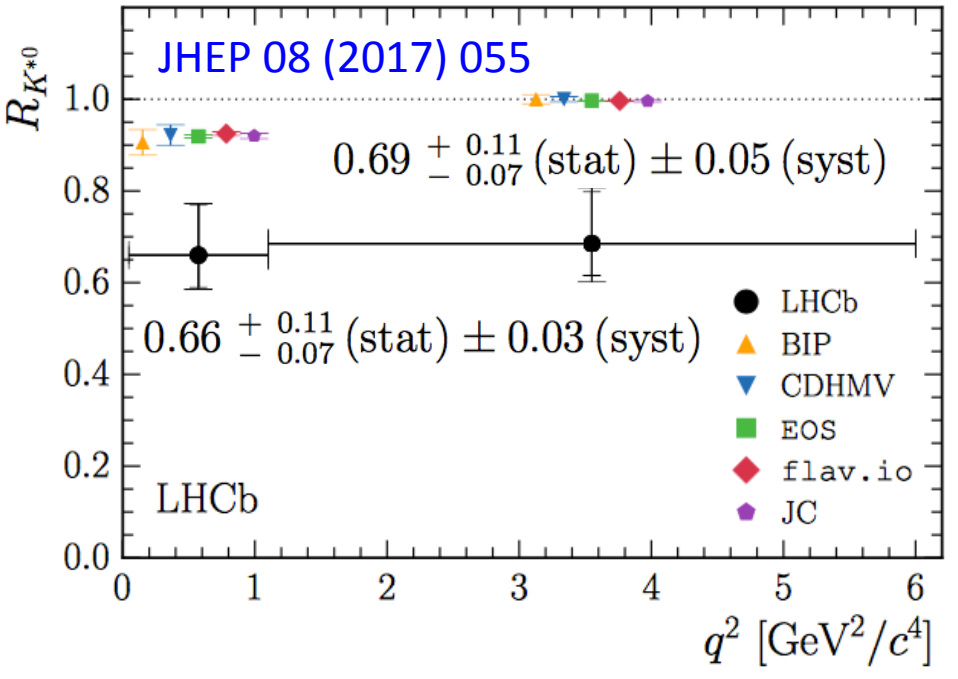
- Measure ratios

  $R_K = BF(B^+ \to K^+\mu^+\mu^-) / BF(B^+ \to K^+e^+e^-)$

  $R_{K^*} = BF(B^0 \to K^{*0}\mu^+\mu^-) / BF(B^0 \to K^{*0}e^+e^-)$

- Theoretically very clean
  - Observation of non-LFU would be a clear sign of new physics
- For the moment at the 3σ-ish level from the SM
- Updates with Run-2 as well as other new measurements with different decay modes expected for next year

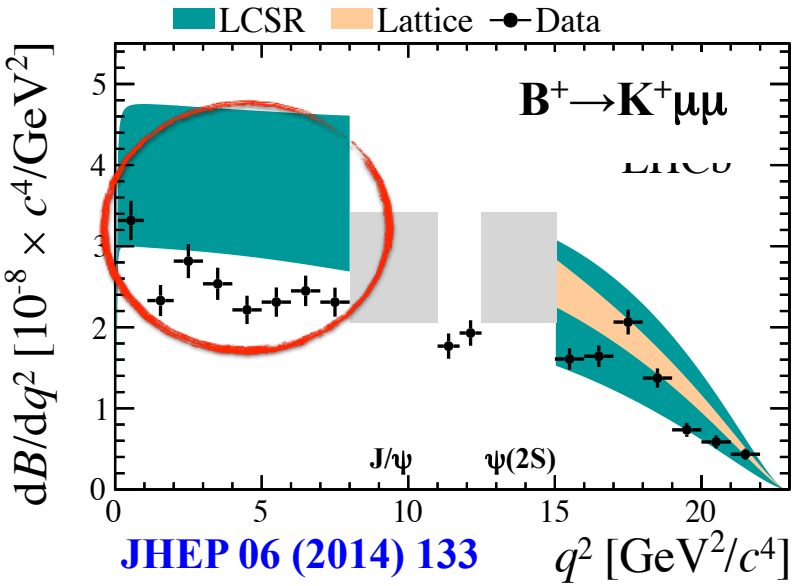




Parallel WG4 talk by Paula

Other anomalies in the $b \to s\ell^+\ell^-$ sector

- Differential branching fractions consistently lower than SM expectations, although predictions are still matter of discussion



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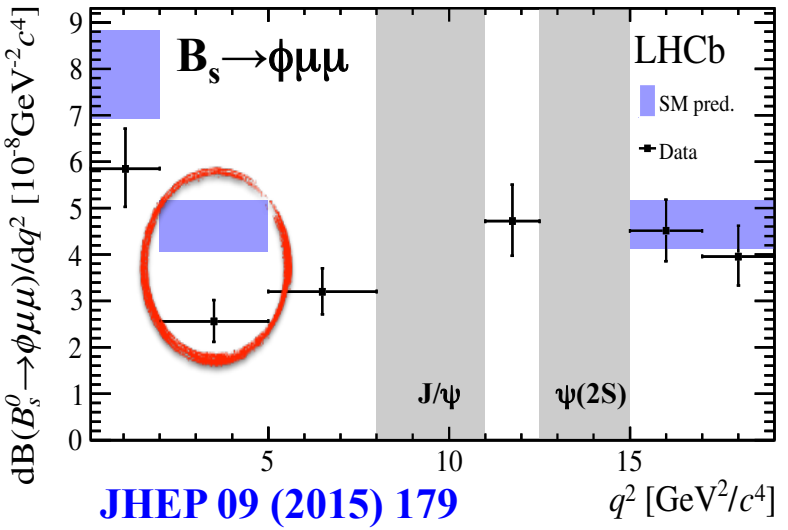

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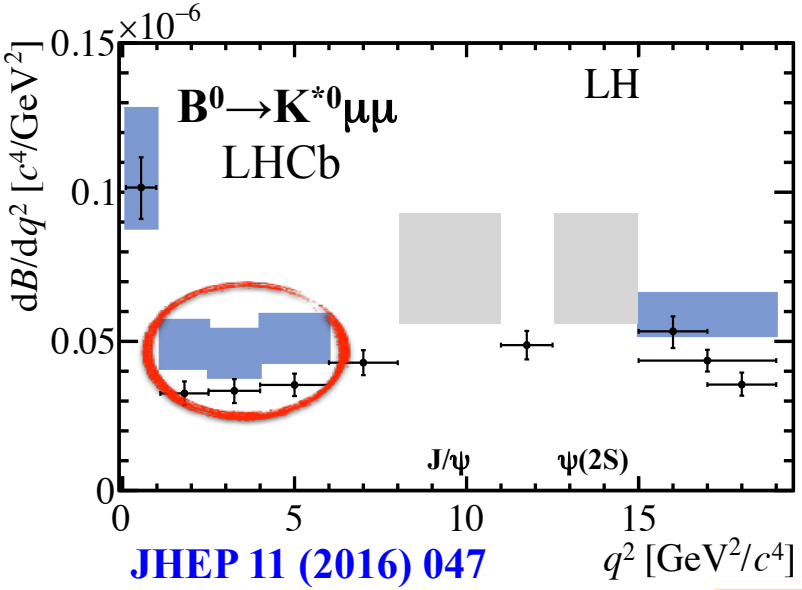

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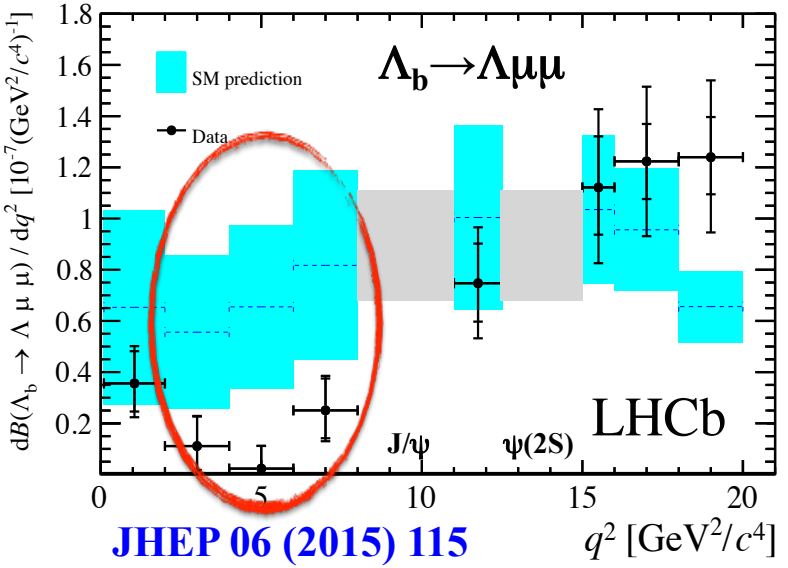

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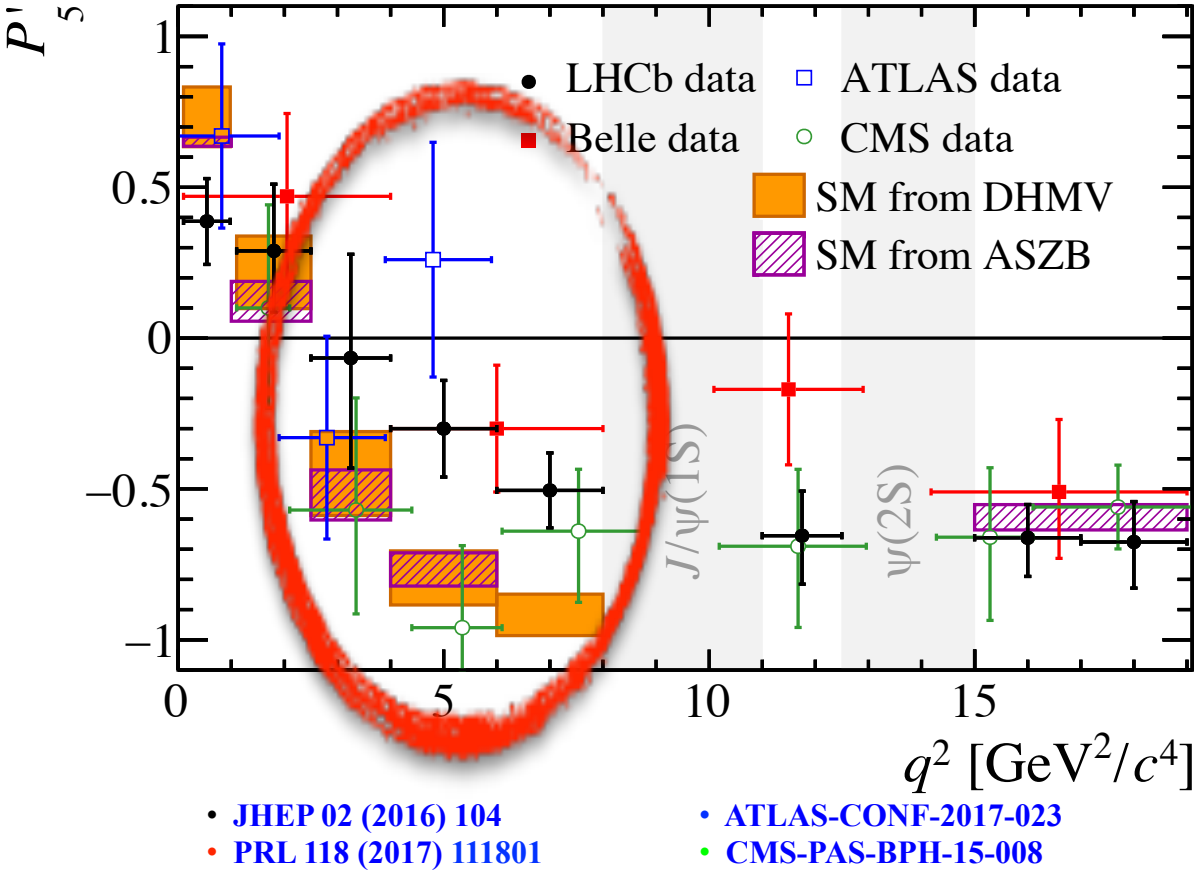
Parallel WG4 talk by Paula

Other anomalies in the $b \to s\ell^+\ell^-$ sector

- Angular analysis of $B^0 \to K^{*0}\mu\mu$
- Can construct less form-factor dependent ratios of observables, like P_5'

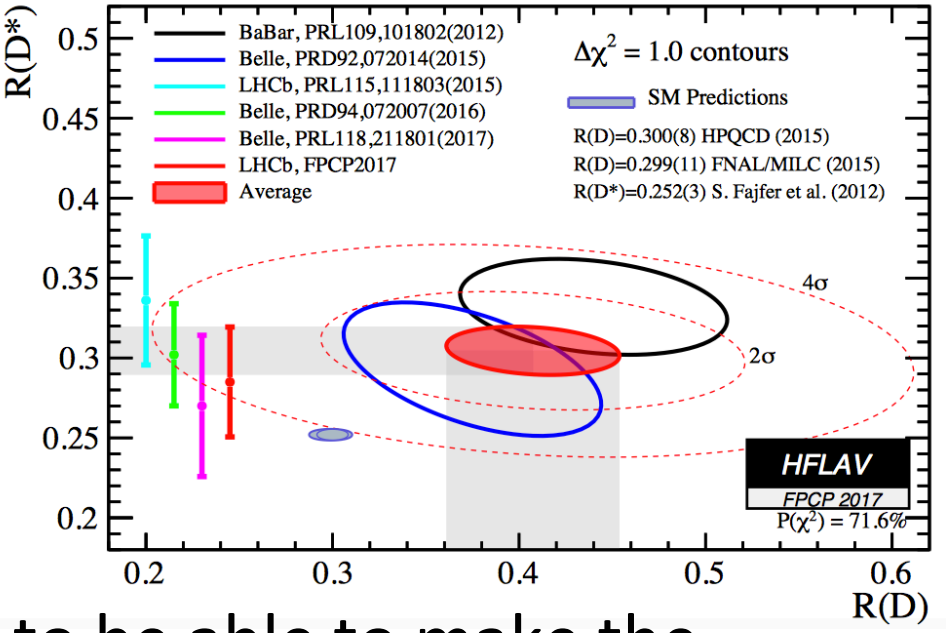


- It is important to remark that global fits by several theory groups take into account up to 90 observables from various experiments, notably including $B \to \mu\mu$ and $b \to s\ell^+\ell^-$ transitions, and nicely get a consistent overall picture

Parallel WG4 talks by Paula, Pavel, Subir

LFU tests in semileptonic *b*-hadron decays

- Measure ratio
  $R_D^{(*)} = BF(B \to D^{(*)}\tau\nu) / BF(B \to D^{(*)}\mu\nu)$
- Measurements of R(D) and R(D*) by BaBar, Belle and LHCb
  - Overall average shows a 4σ discrepancy from the SM
  - LHCb has recently demonstrated to be able to make the measurement also with 3-prong τ decays [arXiv:1708.08856]



- LHCb can also perform measurements with other *b* hadrons
  - Recent determination of $R(J/\psi) = BF(B_c \to J/\psi\tau\nu) / BF(B_c \to J/\psi\mu\nu)$ at about 2σ from the SM
  - Other modes with B_s and Λ_b decays will also come

Parallel WG4 talk by Paula

Spectroscopy

Tetraquarks and pentaquarks

- Sector in great expansion in the last decade
  - A renaissance of QCD in the non-perturbative regime
- Several "exotic" candidates have been identified and are now under the magnifying glass of experiments
  - Lots of work still needed to clarify the global picture and understand the nature of these states

Parallel WG4 talks by Marco Pappagallo, Pavel, Subir

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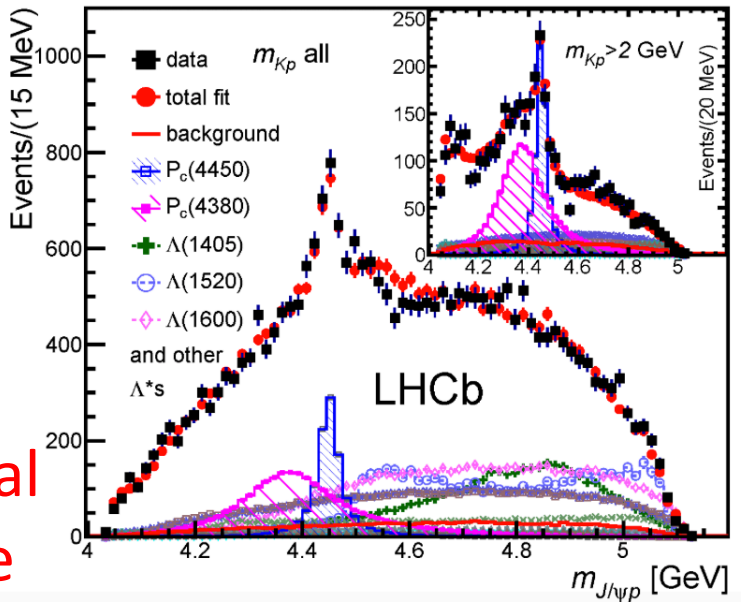

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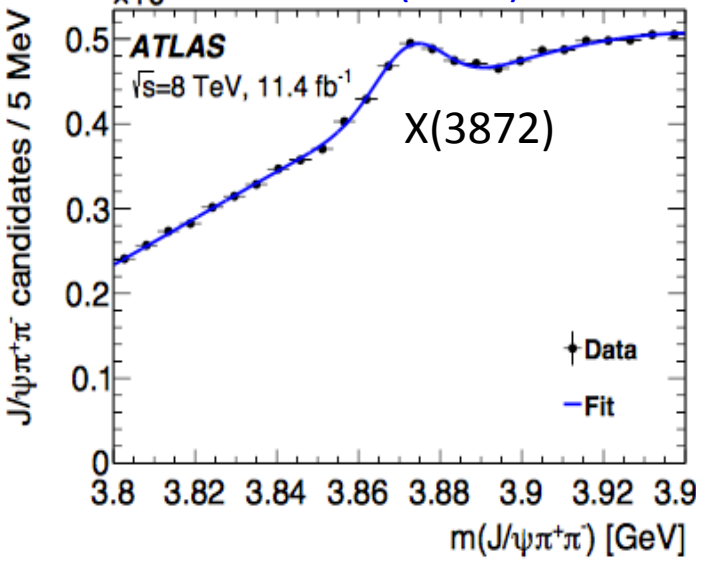

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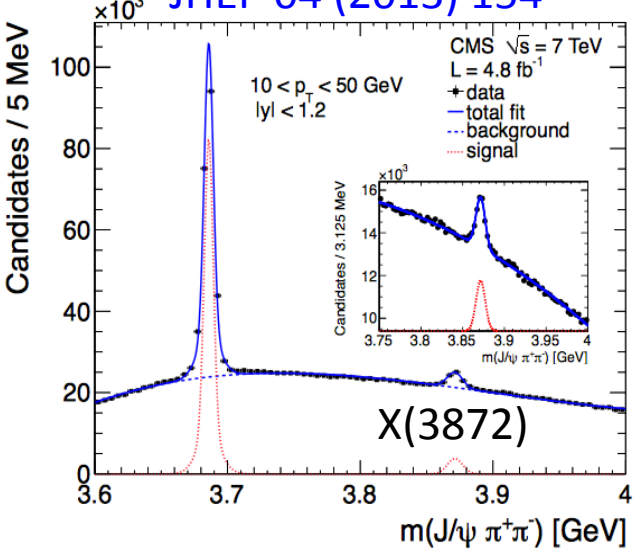
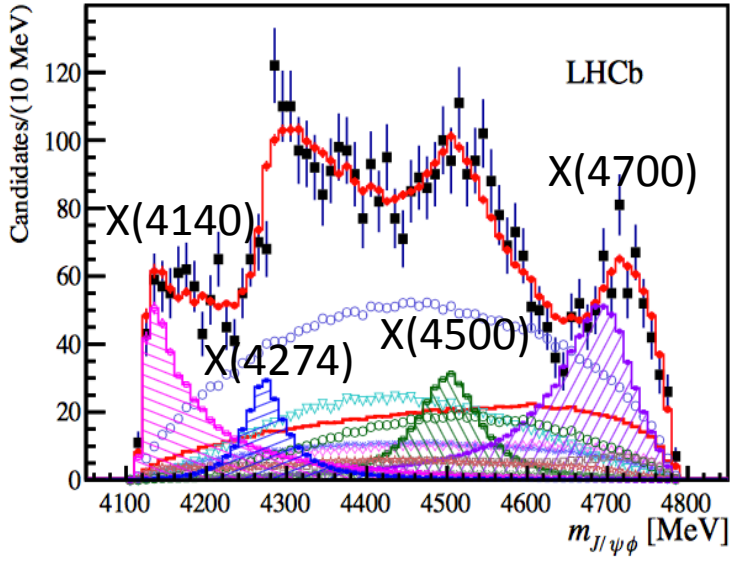


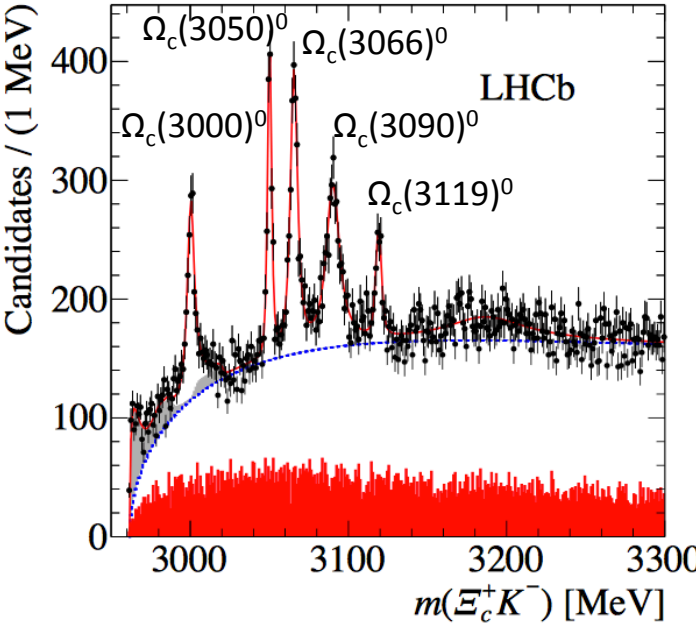
PRL 118 (2017) 022003



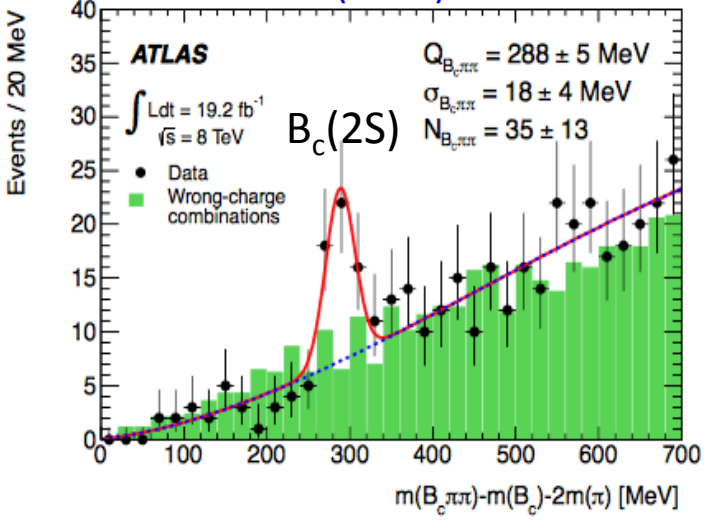
Other observations and measurements

- "Unexpected" observations of new excited states, $B_c(2S)$, Ω_c excitations
- First observation of a doubly-charmed baryon, the Ξ_{cc}^{++}
- Precision measurements of masses and widths of χ_{c1} and χ_{c2} mesons via a newly observed decay mode ($\chi_{c2} \to J/\psi\mu\mu$)

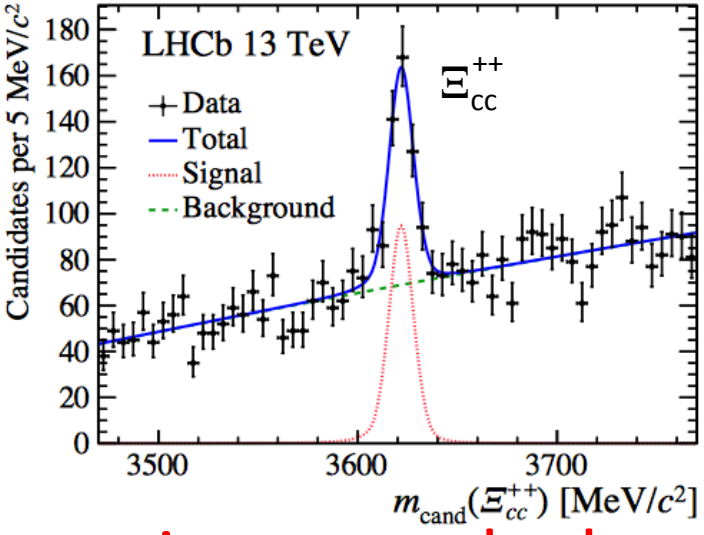
PRL 118 (2017) 182001

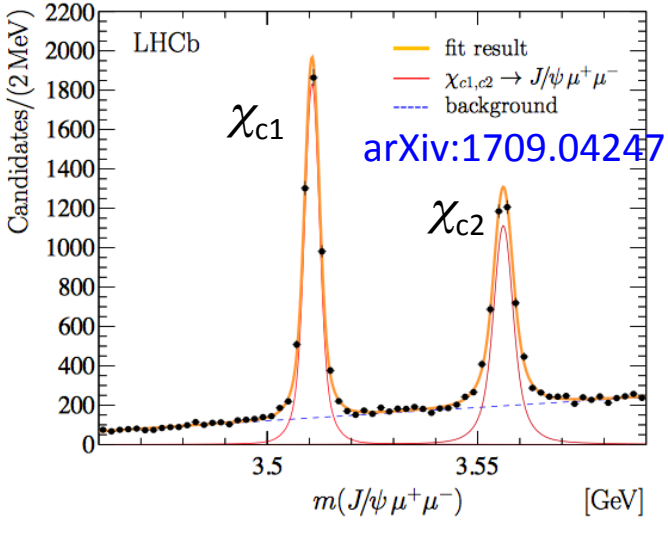


PRL 113 (2014) 212004



PRL 119 (2017) 112001





- We need to keep pursuing strongly the spectroscopy programme in the present and future LHC phases

(some)
Long-term prospects

LHC luminosity prospects

	LHC era			HL-LHC era	
	Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2021-24)	Run 4 (2027-30)	Run 5+ (2031+)
ATLAS, CMS	25 fb^{-1}	150 fb^{-1}	300 fb^{-1}	⟶	3000 fb^{-1}
LHCb	3 fb^{-1}	9 fb^{-1}	30 fb^{-1}	50 fb^{-1}	*300 fb^{-1}

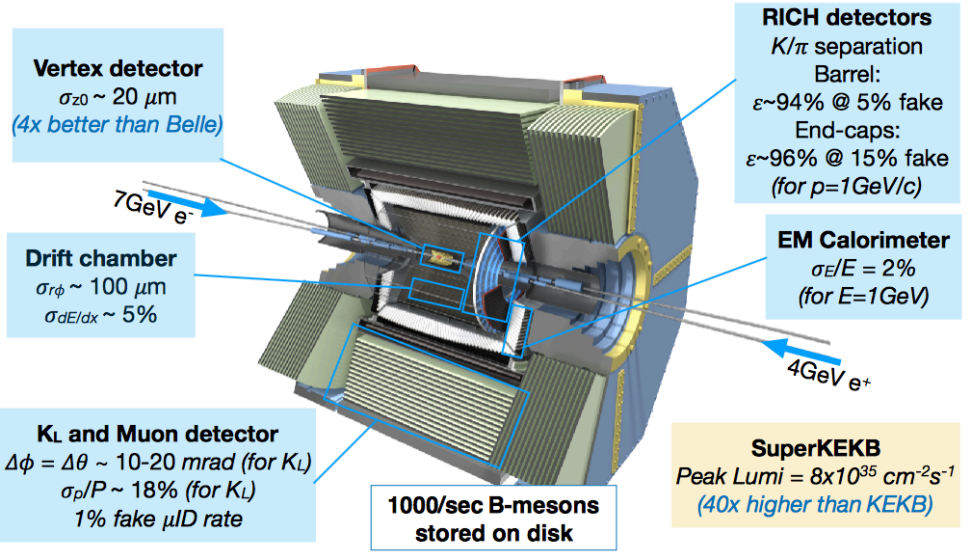
* assumes a future LHCb upgrade to raise the instantaneous luminosity to $2x10^{34}$ $cm^{-2}s^{-1}$

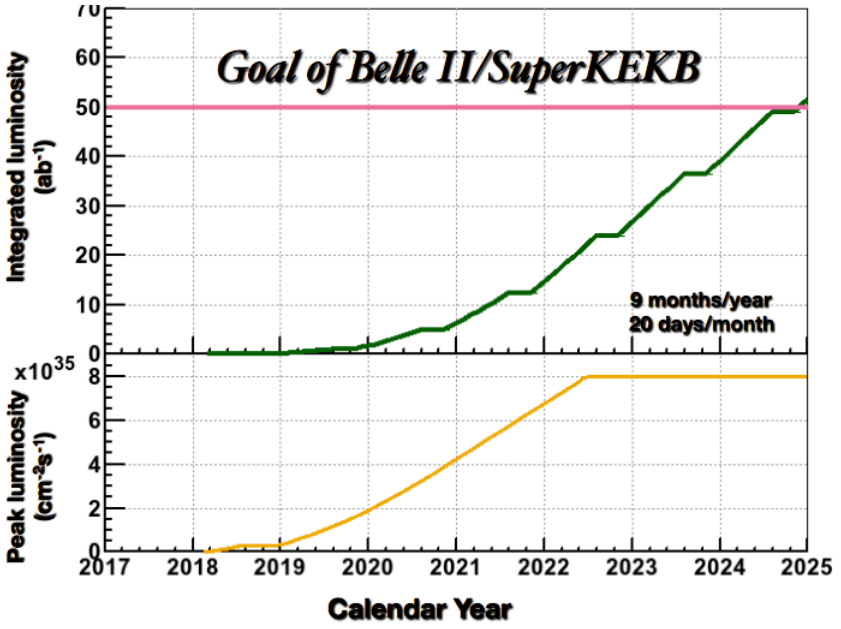
- A first LHCb upgrade comes already in LS2 (to raise the instantaneous luminosity to $2x10^{33}$ $cm^{-2}s^{-1}$), whereas the HL ATLAS and CMS upgrades come in LS3
- LHCb has submitted at the beginning of 2017 an Expression of Interest for a further upgrade during LS4 to reach $2x10^{34}$ $cm^{-2}s^{-1}$

CERN-LHCC-2017-003 https://cds.cern.ch/record/2244311

Belle-II close to take off

- Very exciting prospects from the SuperKEKB machine and new Belle-II detector
- An integrated luminosity of 5 ab^{-1} will be collected by 2021, and 50 ab^{-1} by 2025
- By around 2021, enough luminosity will be available to perform very competitive measurements
- There are important areas, especially with neutrals and missing energy modes, where Belle-II will provide crucial complementary measurements in the flavour sector



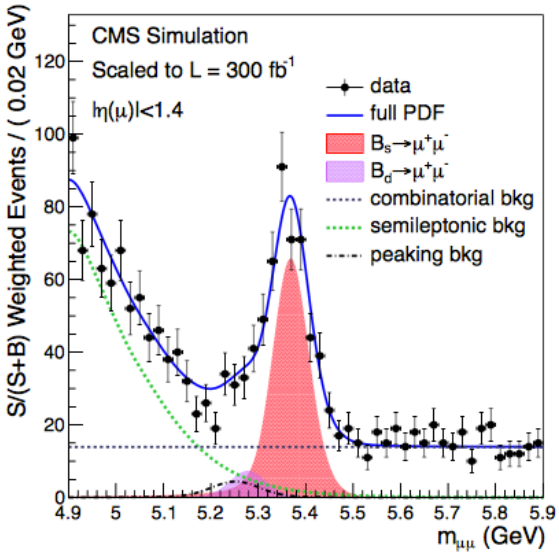


Parallel WG4 talk by Pablo Goldenzweig

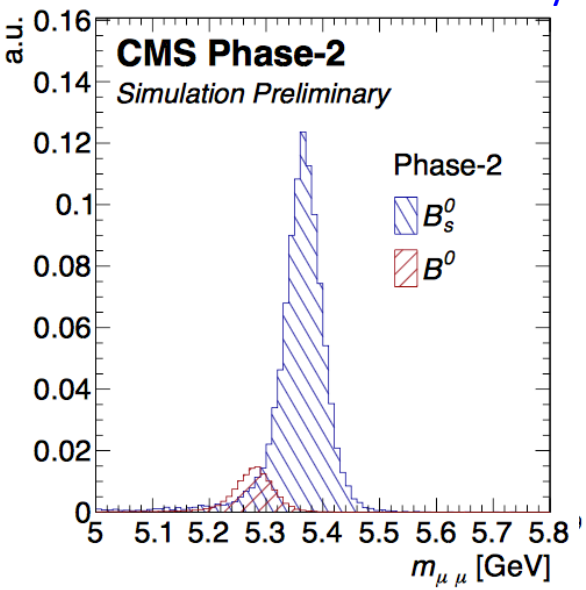
Prospects for $B \to \mu\mu$

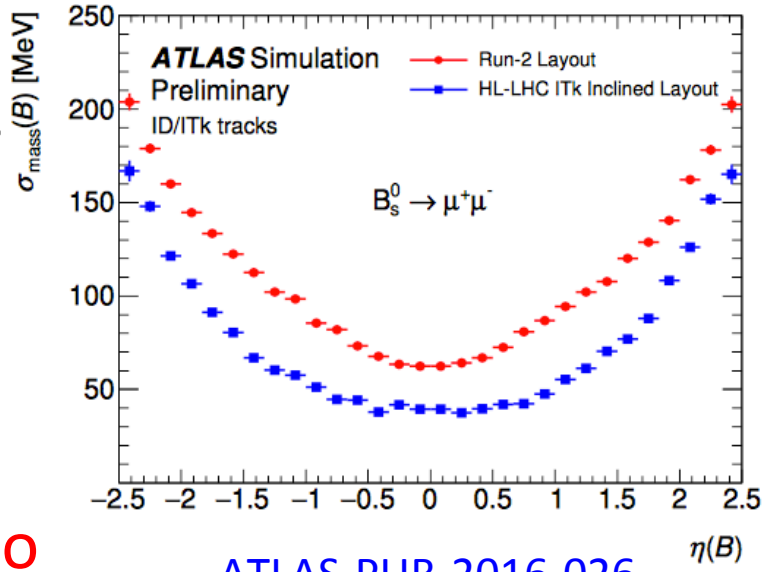
- CMS has shown that a Phase-II trigger for $B \to \mu\mu$ can have an efficiency comparable to that of Run 1, and with a manageable rate despite the huge increase in luminosity
- Furthermore, improvements in the tracker, both in ATLAS and CMS, will considerably improve the mass resolution in Phase-II, allowing for a better separation of B^0 and B_s signals
- Assuming a future LHCb upgrade to reach 300 fb^{-1} in Run 5, the three experiments together have the potential to reach a relative uncertainty on the the ratio of B^0 to B_s branching fractions at better than 10%

CMS PAS FTR-14-015



CMS TDR 17001 Preliminary



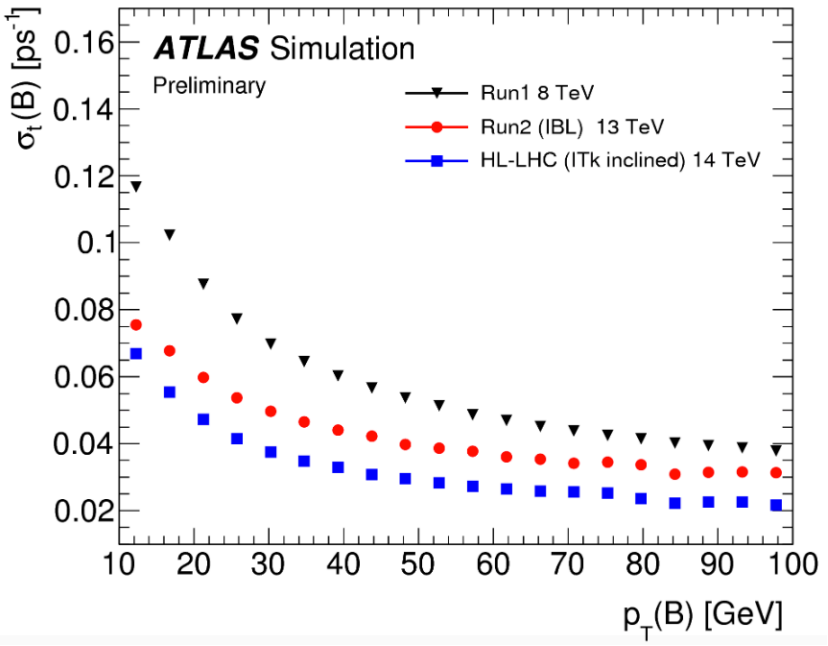


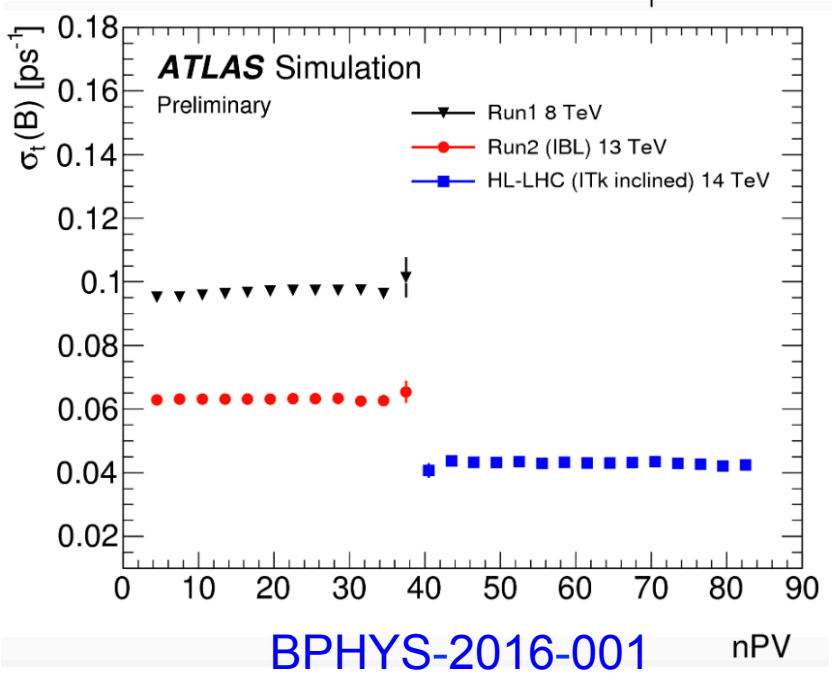
ATLAS-PUB-2016-026

Parallel WG4 talks by Paula, Pavel, Subir

Prospects with $B_s \rightarrow J/\psi\phi$

- ATLAS made studies to assess the improvements in the decay time resolution expected for Phase-II with pileup up to 200
- The definition of precise sensitivities is more difficult as other ingredients need to be studied, such as flavour tagging performances
- However, assuming for LHCb an upgrade to reach 300 fb^{-1}, a precision on ϕ_s at better than 3 mrad by the three experiments together will be reachable at the LHC



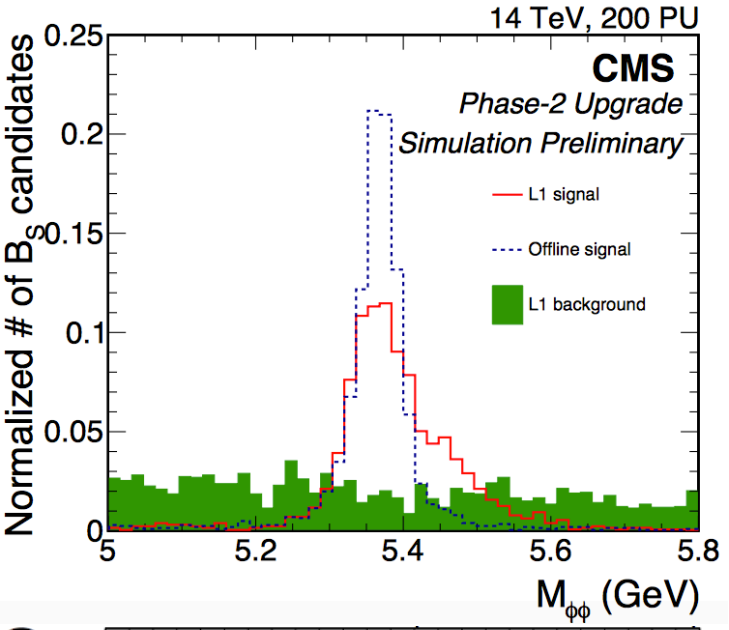


BPHYS-2016-001

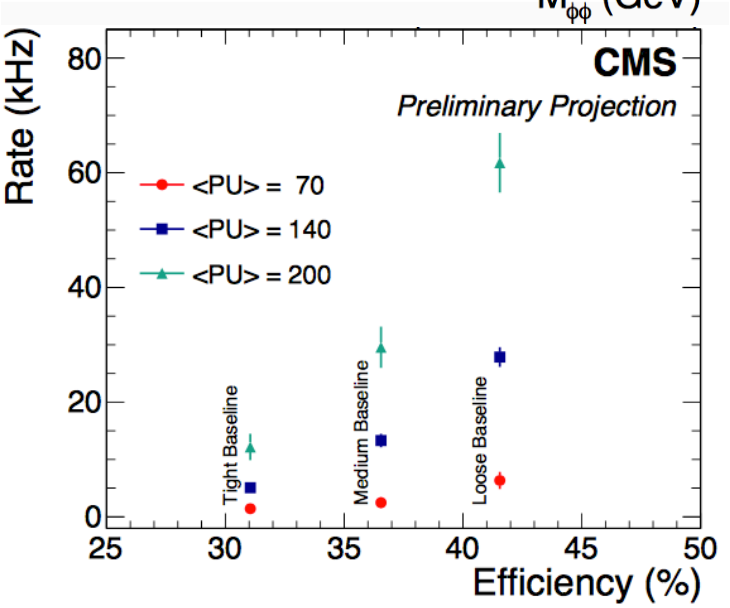
Parallel WG4 talks by Francesca, Pavel

Prospects with $B_s \rightarrow \phi\phi$

- This is an alternative path to ϕ_s, but with a loop-mediated decay that can be affected by new physics also in the decay amplitude
- CMS performed a study to understand the feasibility of triggering in phase two on $B_s \rightarrow \phi\phi \rightarrow (K^+K^-)(K^+K^-)$
  - A rate of about 10 kHz is within the acceptable limit
  - For the scenario with 200 pileup events this rate can only be sustained for a moderate signal efficiency
- Assuming for LHCb an upgrade to reach 300 fb^{-1}, a precision on ϕ_s from this mode at better than 8 mrad can be reached at the LHC



CMS TDR 17001 Preliminary

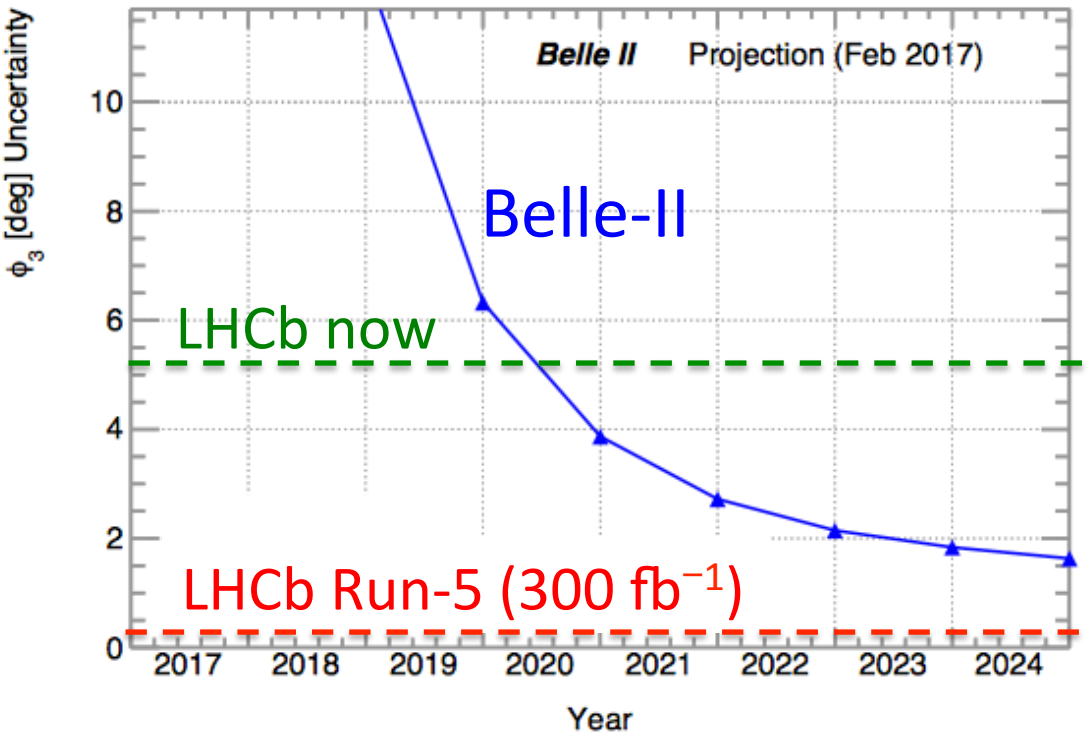


CMS PAS FTR-16-006

Parallel WG4 talks by Francesca, Subir

Prospects for γ

- Belle-II will be in the game well before the start of HL-LHC
- LHCb will have more precise results in fully-charged final states, but might become more competitive in neutral modes too with improvements in the calorimeter
- Belle-II targets a precision on γ of about 2^{o} at the end of the data taking, whereas with an LHCb upgrade to reach 300 fb^{-1}, a precision at better than 0.4^{o} is expected



Parallel WG4 talk by Francesca

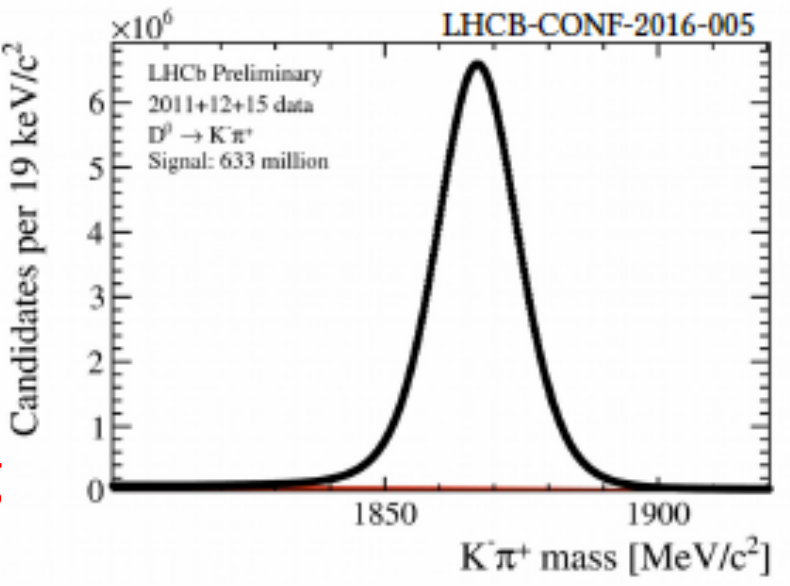
Prospects with flavour anomalies

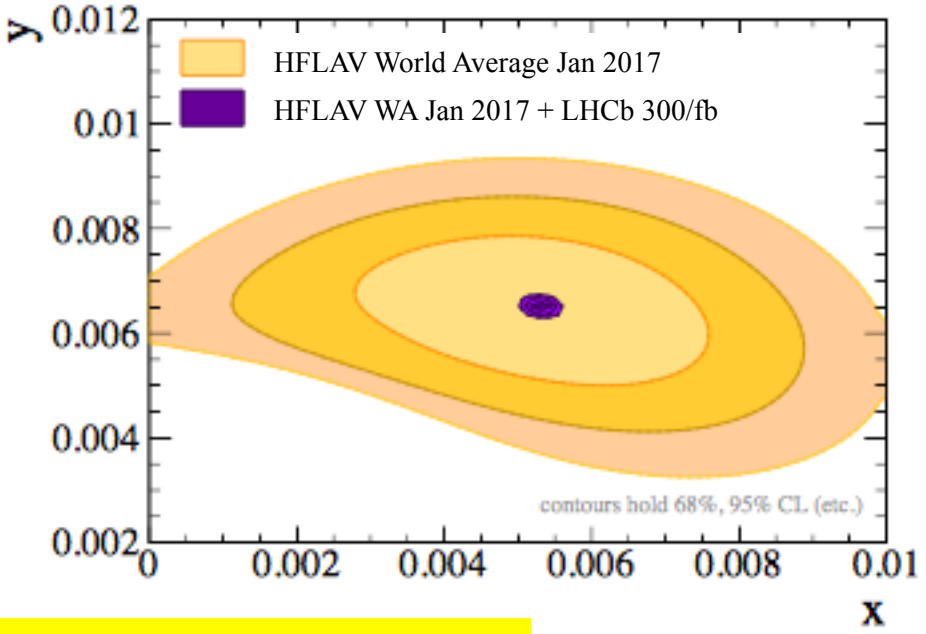
- If the present hints for discrepancies from the SM will become strong evidences or even observations with Run-2 data, and then Belle-II will provide an independent confirmation, new physics will be established well in advance of HL-LHC, both in $b \to s\ell^+\ell^-$ and semitauonic sectors
- But then it will be of paramount importance to draw a full picture with all *b* hadrons and available decay modes in order to pinpoint the sources of new physics, including those with much lower rates not measureable without extreme luminosities
  - e.g., $B_s \to \phi\mu\mu$ flavour-tagged time-dependent analysis and study of $b \to d\ell^+\ell^-$ transitions like $B_s \to \bar{K}^{*0}\ell^+\ell^-$ and $B^0 \to \rho^0\ell^+\ell^-$

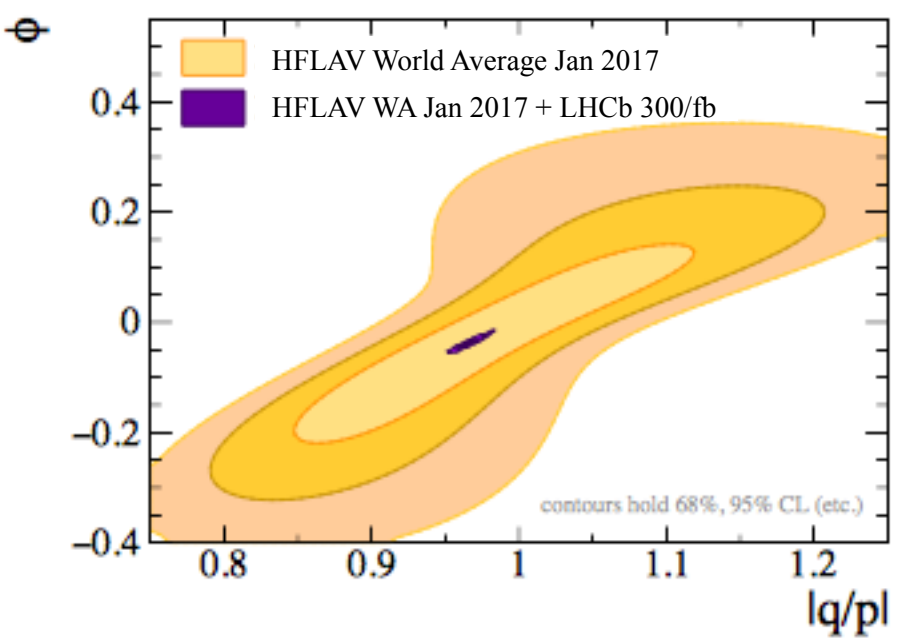
Parallel WG4 talk by Paula

Prospects with charm and strange physics

- Billions of charm and strange hadrons
  - Production rates of tens and hundreds of MHz will enable an incredible statistical precision to be reached
- An LHCb upgrade to get 300 fb^{-1} will make precision measurements of *CP* violation in charm → no other existing or planned experiment can collect such large charm samples







Parallel WG4 talk by Francesca

Concluding remarks

- In the current state with fundamental physics, it is necessary to have a programme as diversified as possible
- If we will see new physics in flavour, e.g. from LHCb in Run 2, we should seek confirmation from multiple experiments
  - Belle-II confirmation if new physics comes from $b \to s\ell^+\ell^-$ and (non) LFU, as well as other measurements not accessible at LHCb like $B \to \tau\nu$
  - ATLAS/CMS in time-dependent B_s physics, $B \to \mu\mu$, ...
- Furthermore, new physics should affect different modes coherently
  - Maintaining the broadest possible physics programme in the long term will be crucial → upgrade of LHCb to further raise the luminosity in Run-5
- Large top-quark production rate can also open new avenues in the flavour sector

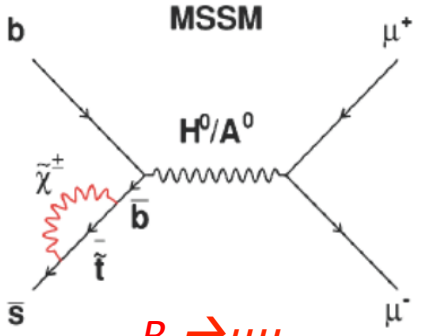
Concluding remarks cont.d

- In the unfortunate event that no direct evidence of new physics pops out of the LHC, flavour physics can play a key role in indicating the way for future developments of elementary particle physics
- If instead new particles will be detected in direct searches, flavour physics will be a fundamental ingredient in understanding the structure of what lies beyond the Standard Model
- In any case, performing precision physics at very high pileup will be a huge detector and reconstruction challenge → let's try hard
- And don't forget: this has been, is and will remain a combined effort between theory and experiments!

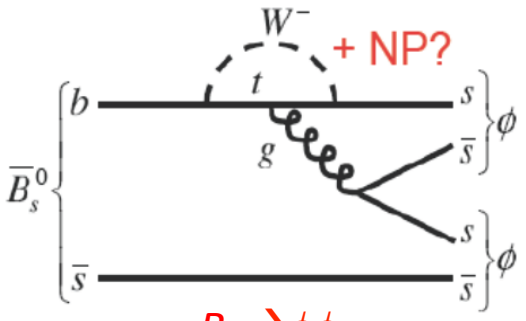
Abandon hope all ye who enter here

New physics searches in the flavour sector

- Instead of searching for NP particles directly produced, look for their indirect effects to low energy processes (e.g. *b*-hadron decays)

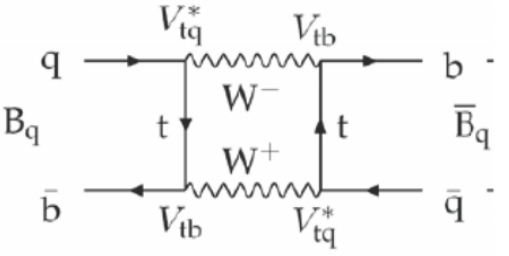


$B_s \to \mu\mu$



$B_s \to \phi\phi$

B-$\bar{B}$ mixing



+ NP?

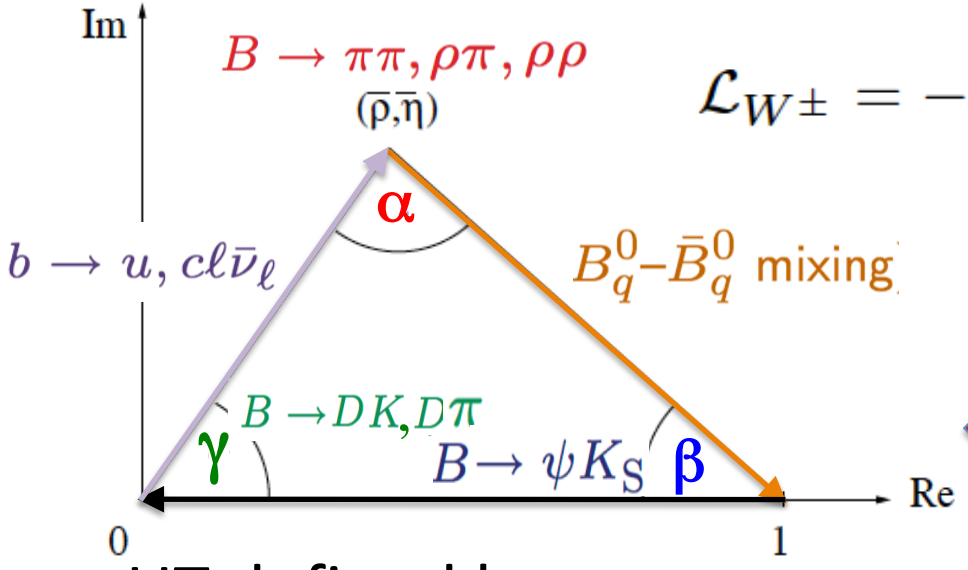
- General amplitude decomposition in terms of couplings and scales → in presence of sizeable SM contributions, NP effects might be hidden

$$A = A_0 \left[c_{SM} \frac{1}{M_W^2} + c_{NP} \frac{1}{\Lambda^2} \right]$$

  - Need high precision measurements of theoretically clean observables
- By studying *CP*-violating and flavour-changing processes, two fundamental tasks can be accomplished
  - Identify new symmetries (and their breaking) beyond the SM
  - Probe mass scales not accessible directly at a collider like LHC

The CKM Unitarity Triangle

$$V_{CKM} = \begin{array}{c} \\ u \\ c \\ t \end{array} \begin{array}{c} \begin{array}{ccc} d & s & b \end{array} \\ \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix} \end{array} + O(\lambda^4)$$



$$\mathcal{L}_{W^\pm} = -\frac{g}{\sqrt{2}}\overline{U}_i\gamma^\mu\frac{1-\gamma^5}{2}(V_{\rm CKM})_{ij}\,D_j W_\mu^+ + h.c.$$

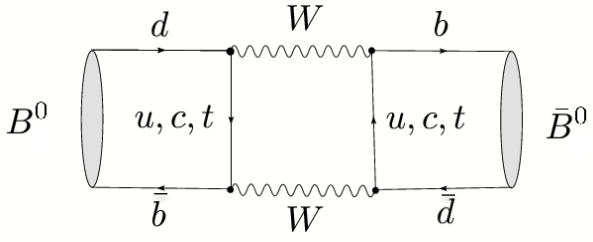
From CKM matrix unitarity

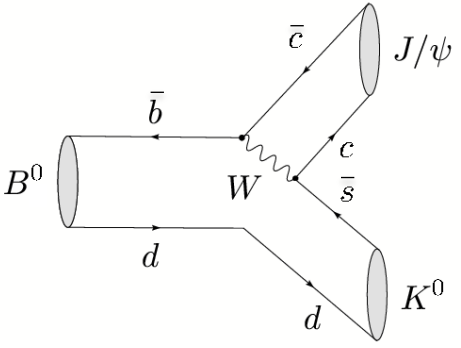
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

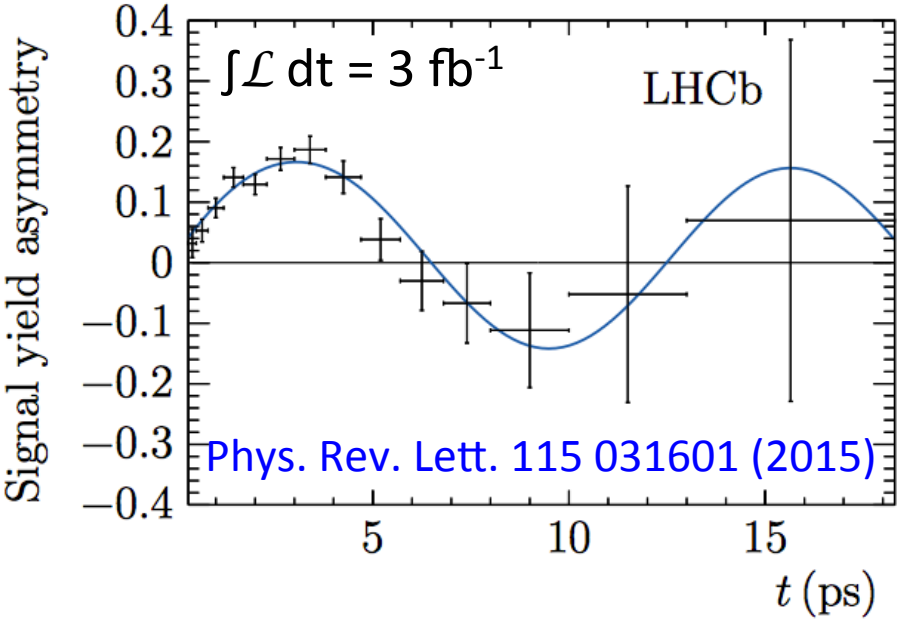
- UT defined by two parameters only → can be over-constrained
- The height (irreducible complex phase $\bar{\eta}$) controls the strength of *CP* violation in the Standard Model

Measurement of sin2β

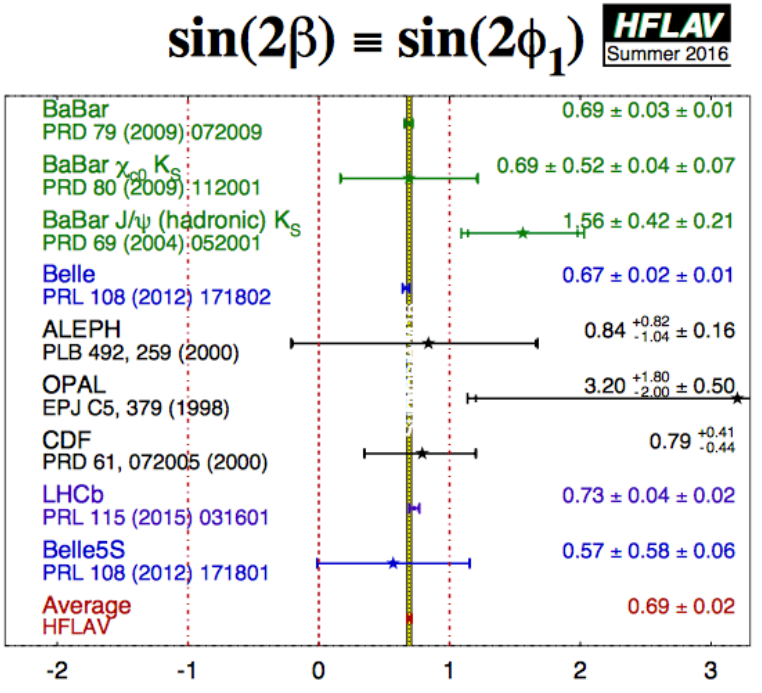
- *CP* violation due to interference between B^0-$\bar{B}^0$ mixing and b→c$\bar{c}$s transitions

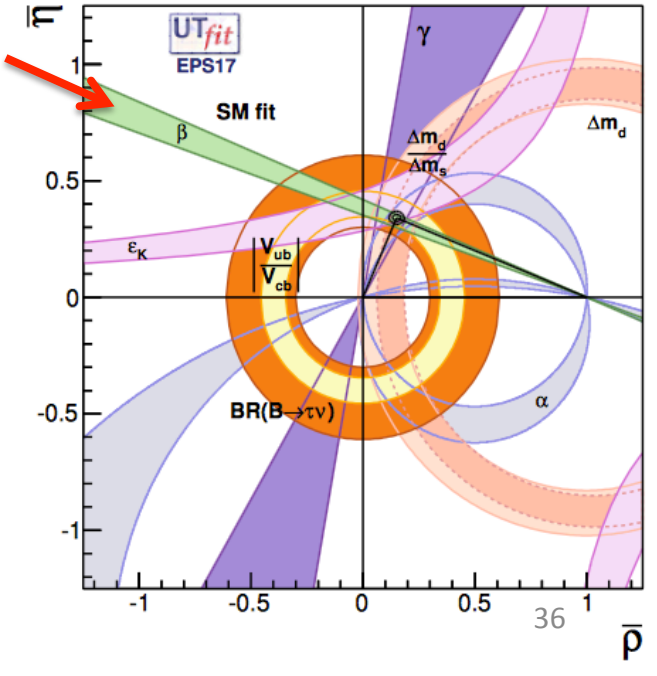






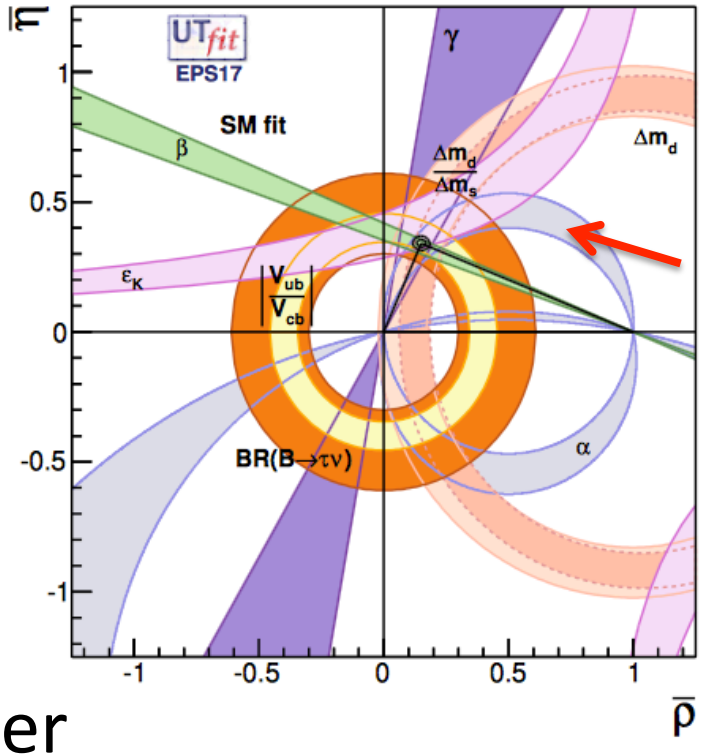
- LHCb has reached the precision of the *B* factories and will surpass that with Run-2 data





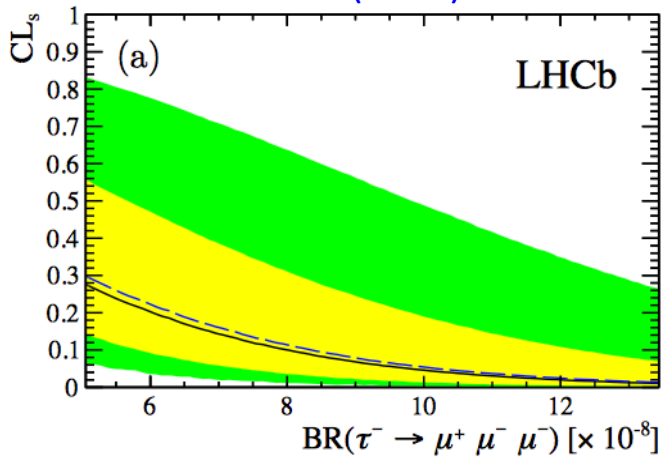
And what about α?

- The angle α is measured via isospin analyses of the $B \to \pi\pi$, $B \to \rho\rho$ and $B \to \rho\pi$ systems
  - E.g. J. Charles *et al.*, arXiv:1705.02981, $\alpha = (86.2^{+4.4}_{-4.0})^{o}$
- An experimental issue is that one needs to measure all possible final states, involving also neutrals
  - Notably difficult is in harsh hadronic environment
- LHCb has been contributing to the world average via $B \to \pi^+\pi^-$ and $B \to \rho^0\rho^0$, but most of the sensitivity so far comes from the *B* factories
- Improvements in the LHCb calorimeter in Run 4/5 would allow LHCb to push this much further



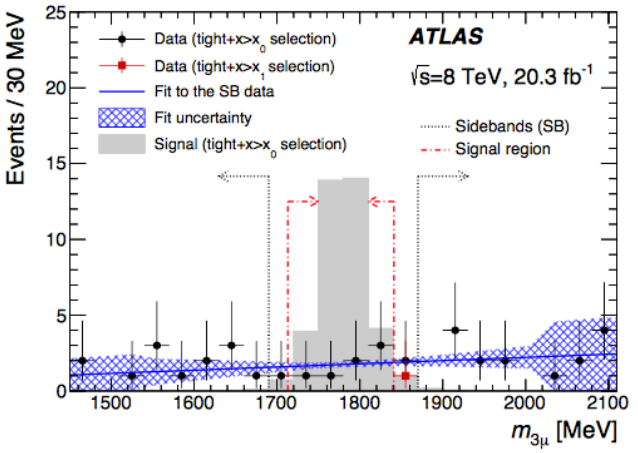
Searches for
$\tau \to 3\mu$, $K_S \to \mu\mu$, $D \to e\mu$, $B \to e\mu$

JHEP 02 (2015) 121



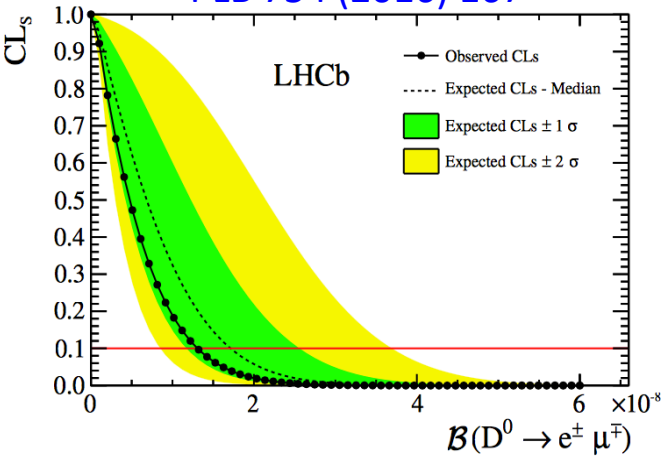
$\mathcal{B}(\tau^- \to \mu^-\mu^+\mu^-) < 4.6\ (5.6) \times 10^{-8}$

EPJC 76 (2016) 232



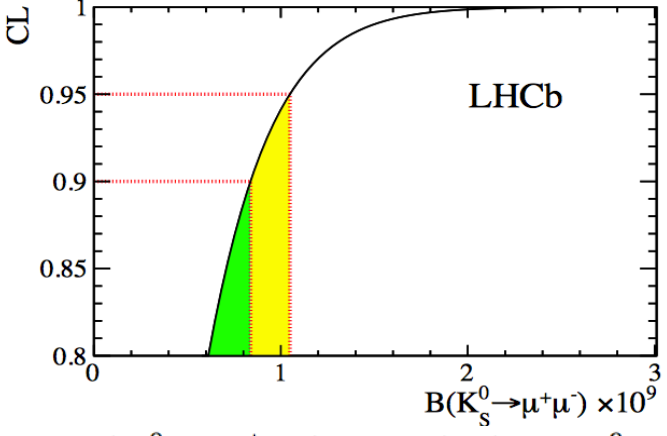
$\mathcal{B}(\tau^- \to \mu^-\mu^+\mu^-) < 3.76 \times 10^{-7}$

PLB 754 (2016) 167



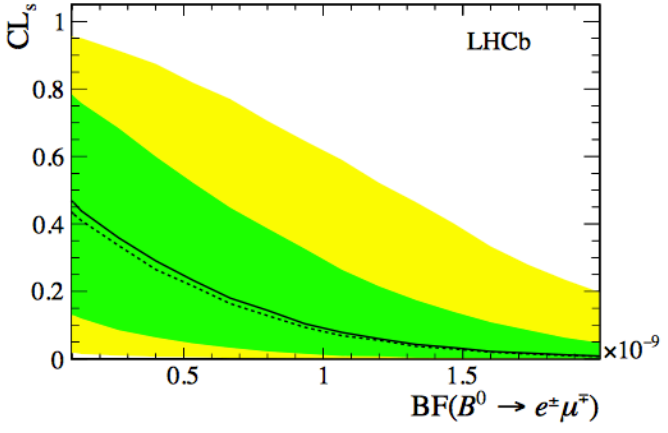
$\mathcal{B}(D^0 \to e^\pm\mu^\mp) < 1.3(1.6) \times 10^{-8}$

EPJC 77 (2017) 678



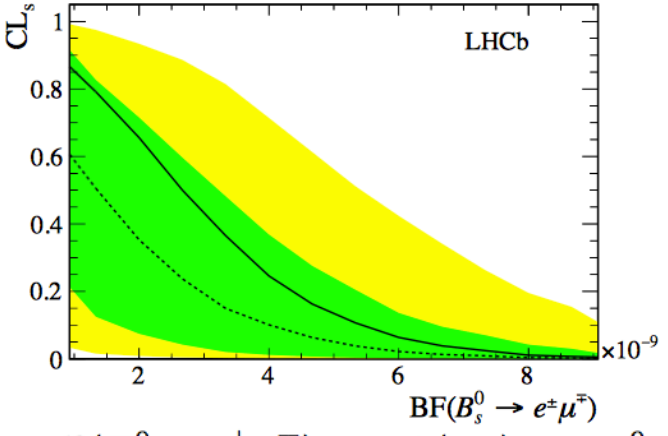
$\mathcal{B}(K_S^0 \to \mu^+\mu^-) < 0.8\ (1.0) \times 10^{-9}$

arXiv:1710.04111



$\mathcal{B}(B^0 \to e^\pm\mu^\mp) < 1.0\ (1.3) \times 10^{-9}$

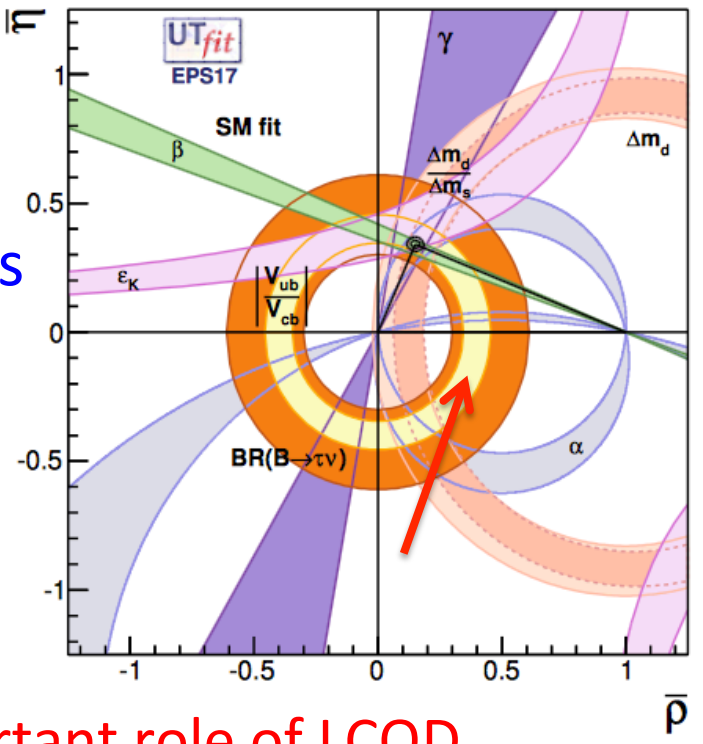
arXiv:1710.04111



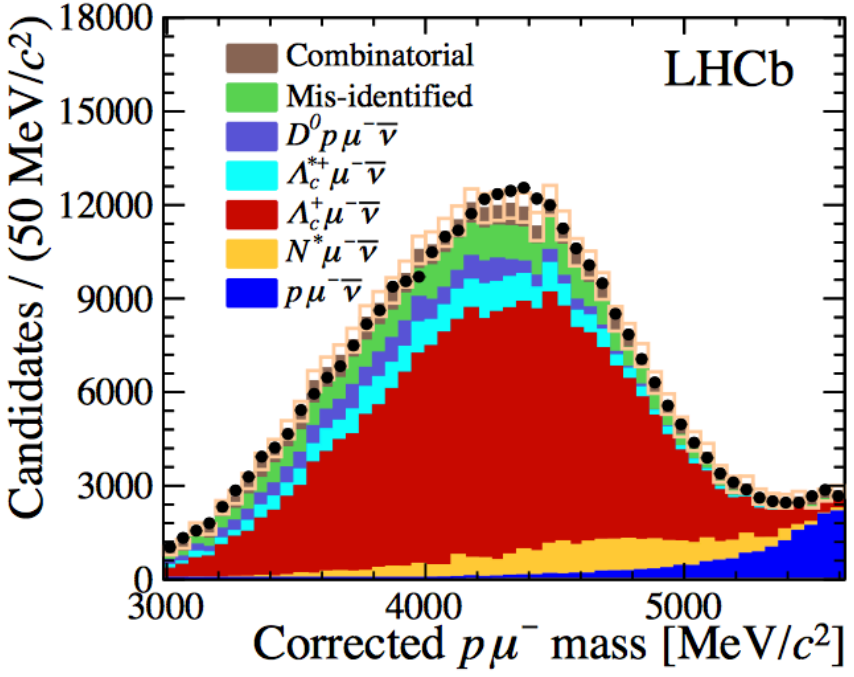
$\mathcal{B}(B_s^0 \to e^\pm\mu^\mp) < 5.4\ (6.3) \times 10^{-9}$

Measurement of $|V_{ub}|/|V_{cb}|$

- Measured at *B* factories and more recently by LHCb using Λ_b semileptonic decays
  - first of a rich programme of measurements with *b*-hadron semileptonics at LHCb



$$R_{exp} = \frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,\mathrm{GeV}/c^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\overline{\nu}_\mu)_{q^2>7\,\mathrm{GeV}/c^2}} = (1.00 \pm 0.04 \pm 0.08) \times 10^{-2}$$



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Important role of LCQD

$$R_{exp} = R_{theory}(|V_{ub}|^2/|V_{cb}|^2)$$

$$R_{theory} = 1.470 \pm 0.115(stat) \pm 0.104(syst)$$

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

Signal $\Lambda_b \to p\mu\nu$ decays

$$N(\Lambda_b \to p\mu^-\overline{\nu}_\mu) = 17687 \pm 733$$

Prospects with $b \to d\ell^+\ell^-$ transitions

- For example, the angular analysis of $B_s \to \bar{K}^{*0}\mu\mu$ with 300 fb^{-1} from LHCb will be more precise than the Run-1 result for $B^0 \to K^{*0}\mu\mu$, enabling a powerful comparison between different flavour transitions
- A time-dependent analysis will become feasible for the mode $B^0 \to \rho^0\ell^+\ell^-$, and with large sample sizes and improved π^0 reconstruction due to an upgraded calorimeter, other relevant modes with neutrals will become accessible