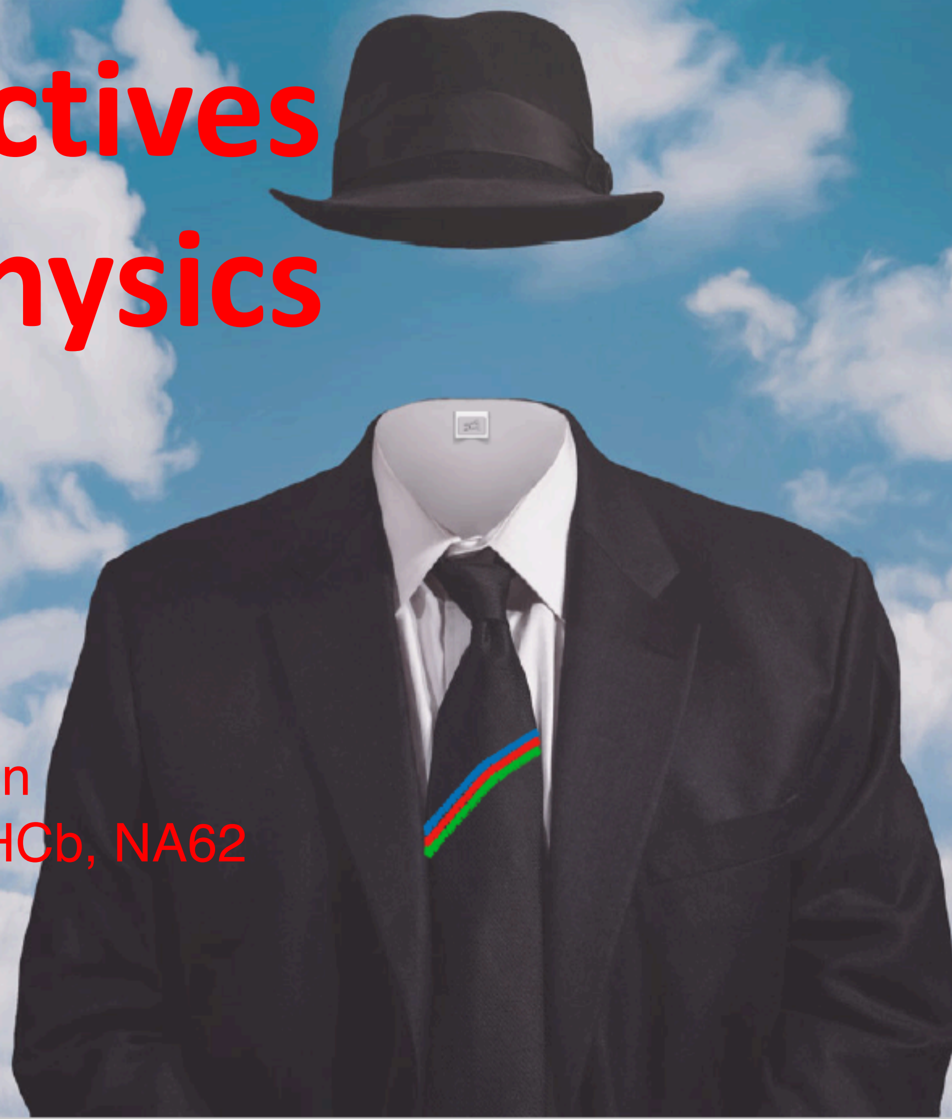
QCD@LHC

Aug 31 - Sept 3 · 2020

Status and perspectives in quark-flavour physics



Vincenzo Vagnoni

INFN Bologna

on behalf of the LHCb collaboration

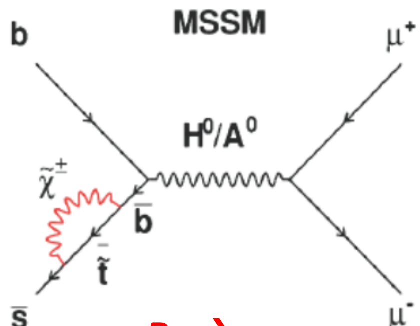
with material from ATLAS, Belle II, CMS, LHCb, NA62

Setting the scene

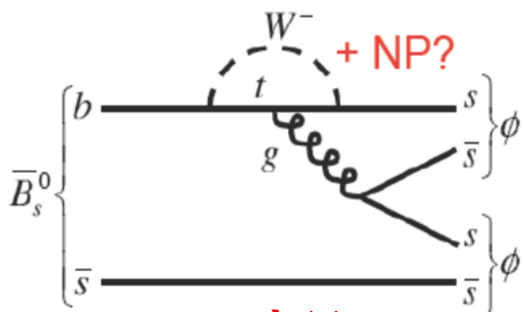
- The Standard Model of particle physics works beautifully up to an energy scale of a few hundred GeV
- However, there are compelling reasons to state its incompleteness, e.g.
  - Missing dark matter candidate
  - Insufficient *CP* violation for dynamical generation of BAU
- As well as more fundamental reasons
  - Why there are three families of quarks and leptons?
  - Why the masses of fundamental particles span several orders of magnitude?
  - How to accommodate gravity into the global quantum picture?
  - …

New physics searches in the flavour sector

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

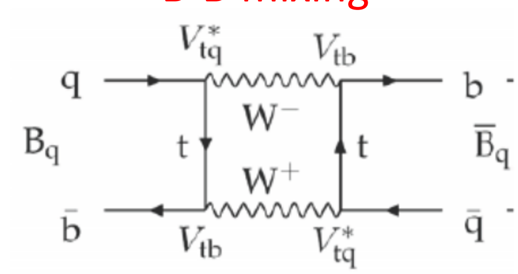


$B_s \to \mu\mu$



$B_s \to \phi\phi$

B-$\bar{B}$ mixing



+ NP?

- General amplitude decomposition in terms of couplings and scales

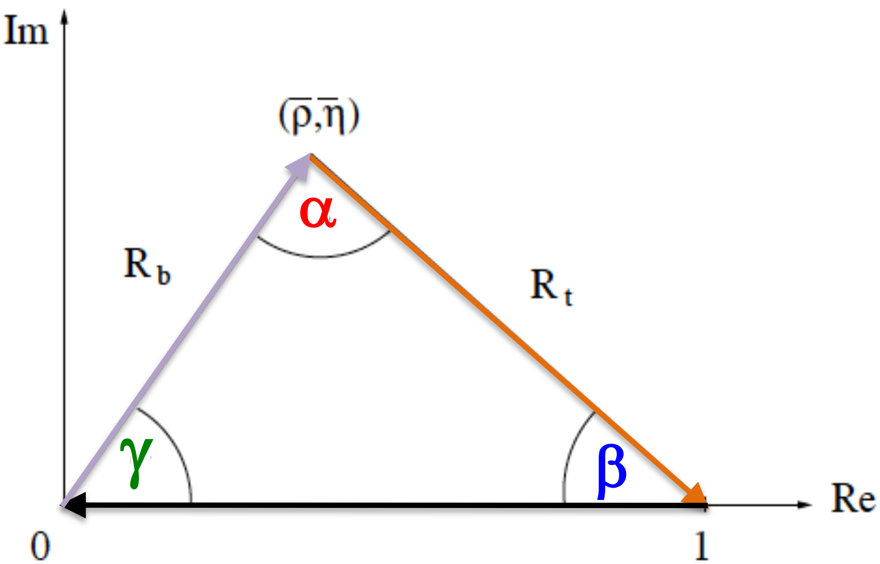
$$A = A_0 \left[c_{SM} \frac{1}{M_W{}^2} + c_{NP} \frac{1}{\Lambda^2} \right]$$

- Two fundamental tasks
  - Identify new symmetries (and their breaking) beyond the SM
  - Probe mass scales not accessible directly at a collider like LHC

The CKM Unitarity Triangle

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

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



From CKM matrix unitarity

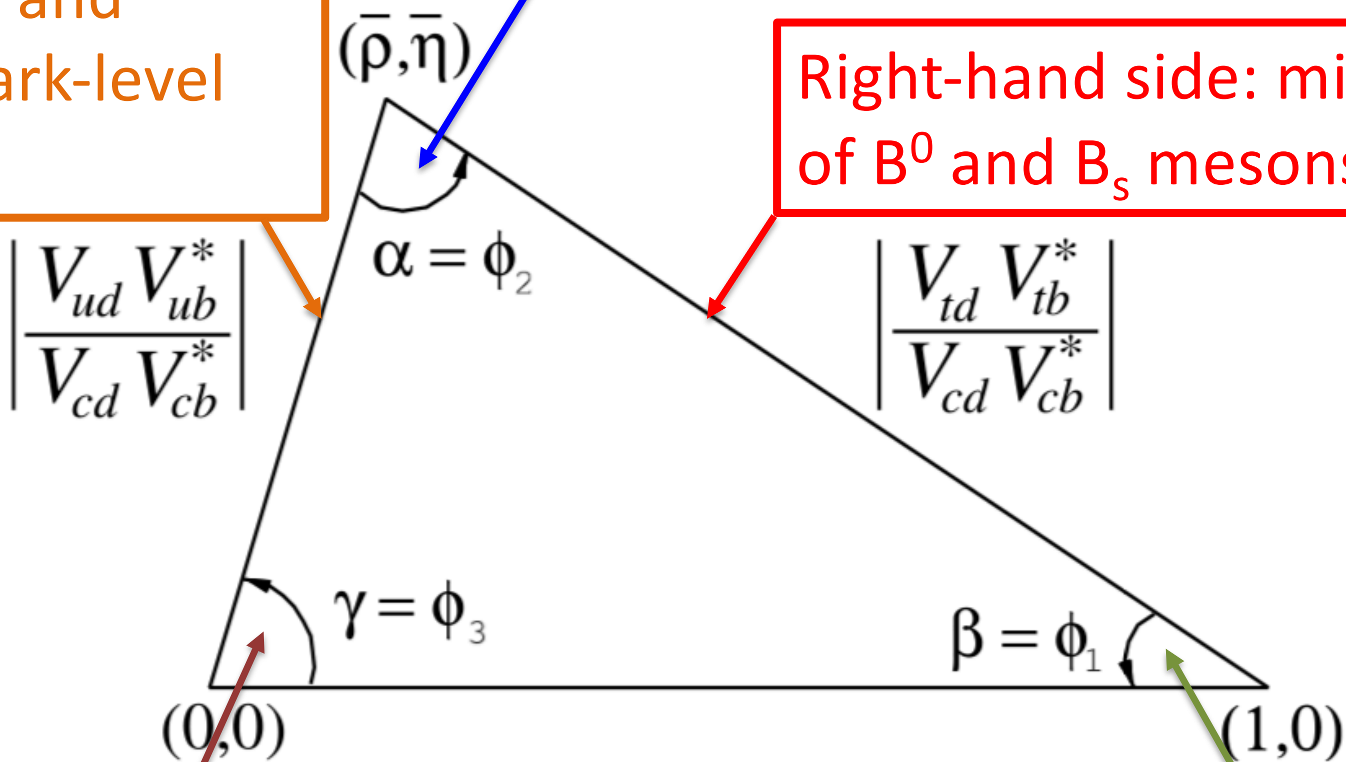
$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$

Overconstraining the unitarity triangle

Left-hand side: rates of decays mediated by $b \to u l \nu$ and $b \to c l \nu$ quark-level processes

Angle α: decay rates and CP violation in $B \to \pi\pi$, $B \to \rho\pi$, $B \to \rho\rho$ decays

Right-hand side: mixing rate of B^0 and B_s mesons



Angle γ: CP violation in $B \to DK$, $B \to D\pi$ decays, …

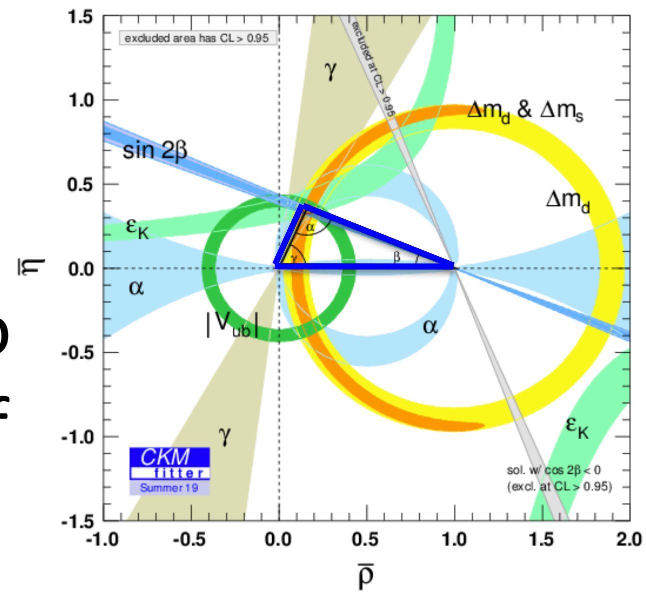
Angle β: CP violation in $B \to c\bar{c}K_S$, $B \to c\bar{c}K_L$ decays, …

- Defined by two parameters only → can be over-constrained by several independent measurements

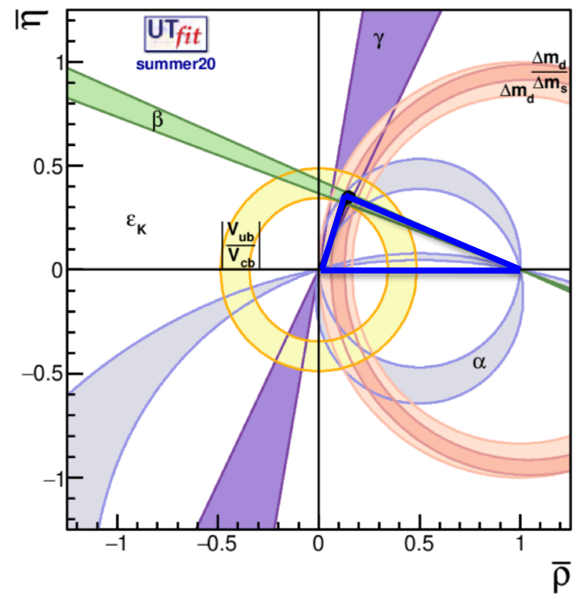
Unitarity triangle today

- Each coloured band defines the allowed region of the apex of the unitarity triangle according to the measurement of a specific process

http://ckmfitter.in2p3.fr

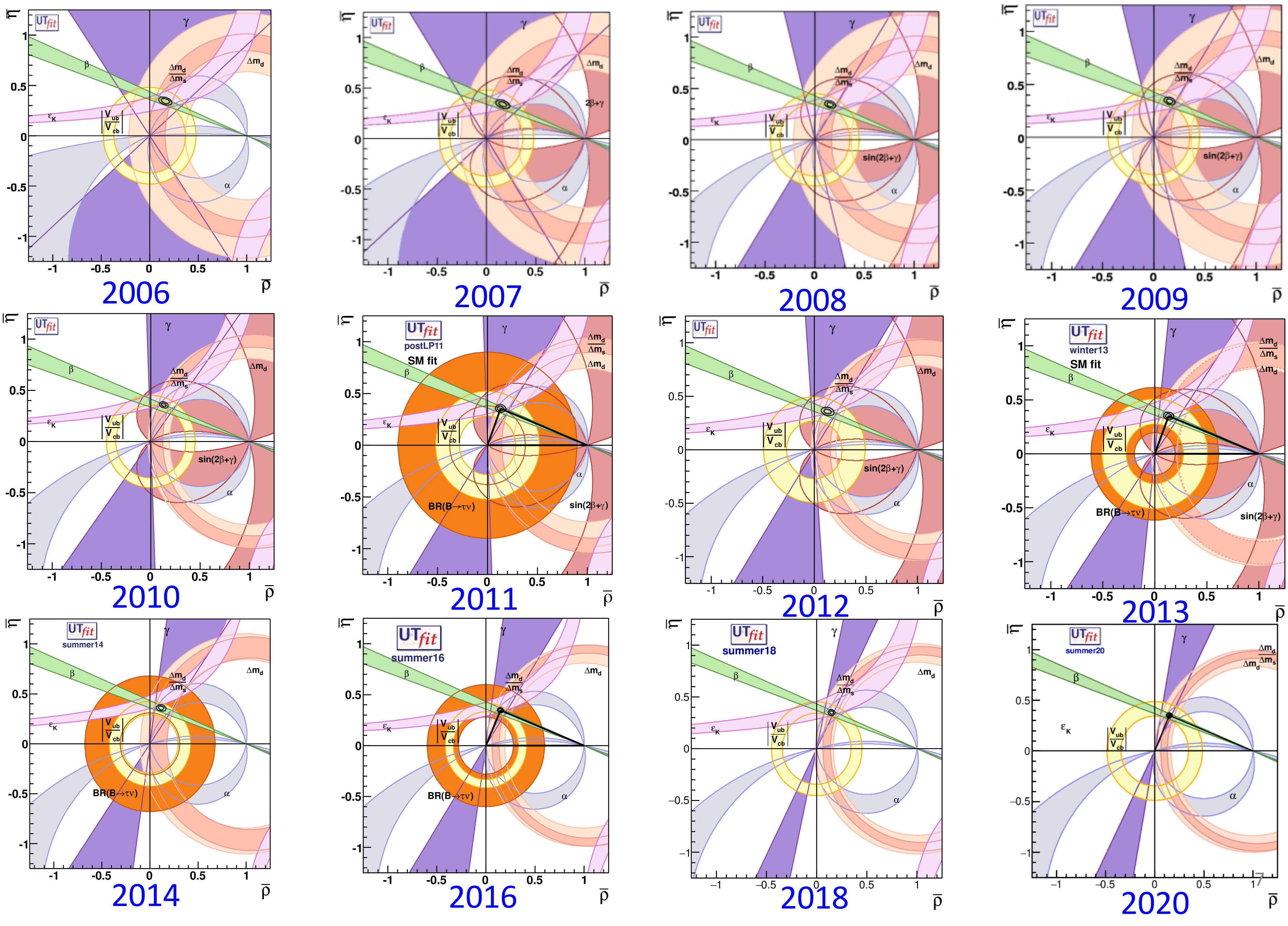


http://www.utfit.org

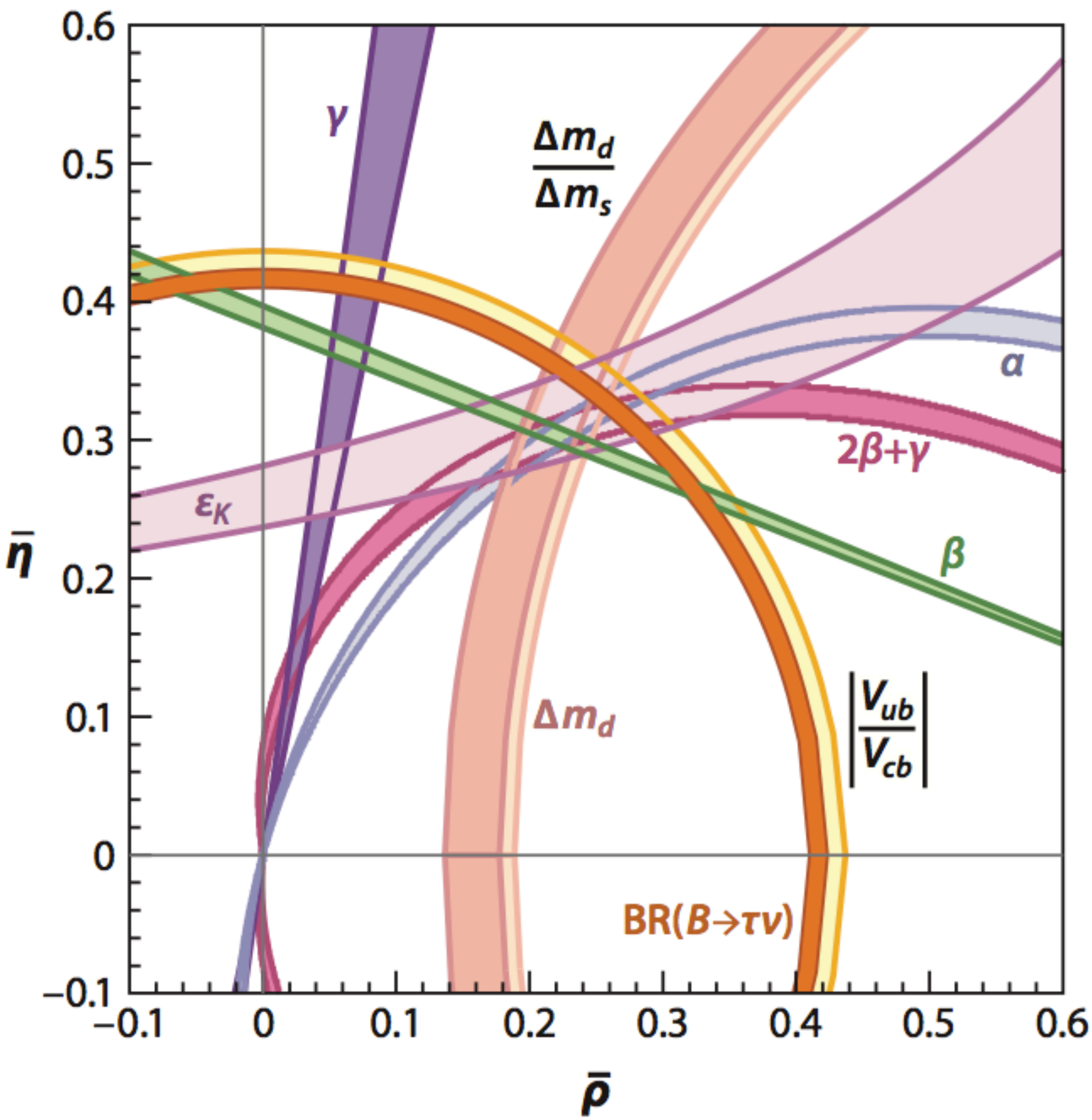


- Incredible success of the CKM paradigm so far
  - All of the available measurements agree in a highly profound way to the current level of precision
  - In presence of BSM physics affecting the measurements, the various contours would not cross each other into a single point
- The quark flavour sector is generally well described by the CKM mechanism → we must look for small discrepancies

It has been a long journey…



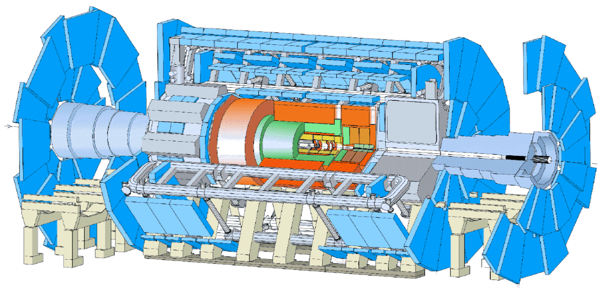
…not yet ended!

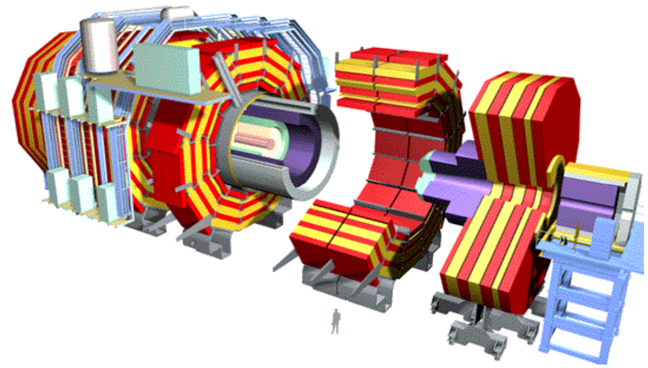


Dream scenario, for illustration only

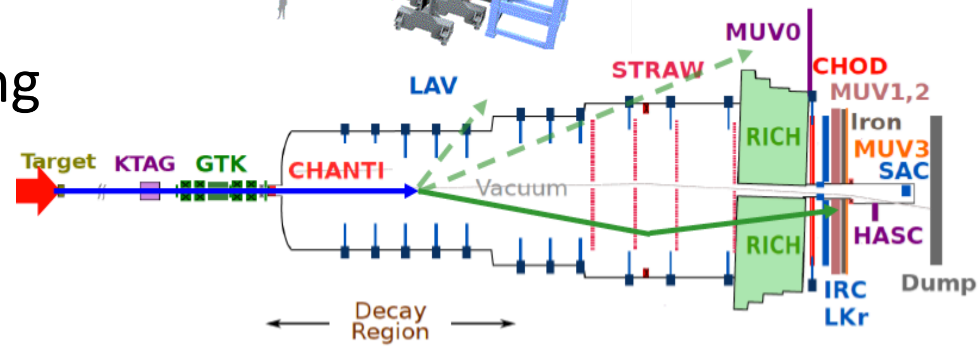
Main players today in quark-flavour physics

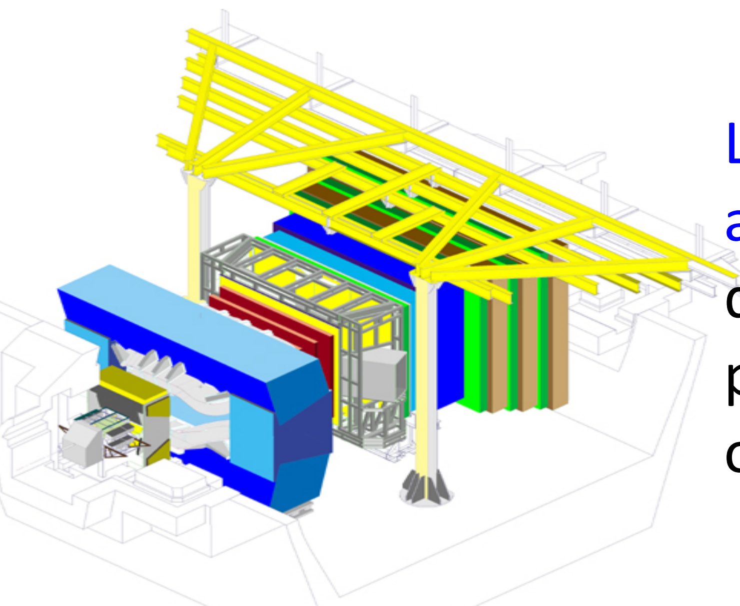
ATLAS and CMS at CERN: measure some relevant B-physics channels, mainly with muons in the final state



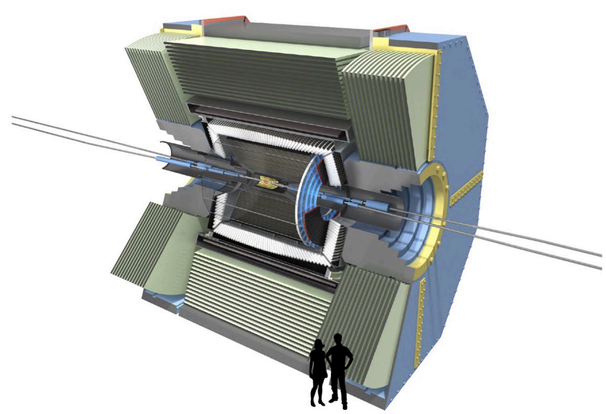


NA62 at CERN: measure the SM branching fraction of $K^+ \rightarrow \pi^+ \nu\nu$ with 10% precision





LHCb at CERN and Belle II at KEK: dedicated detectors for flavour physics with wide range of measurements

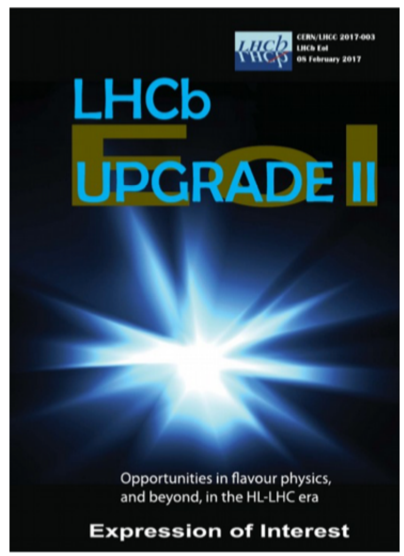


Upgrades at the LHC

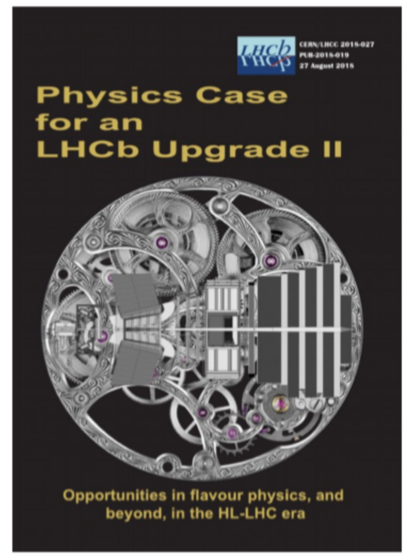
	LHC era			HL-LHC era	
	Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2021-24)	Run 4 (2027-30)	Run 5+ (2031+)
ATLAS, CMS	25 fb^{-1}	150 fb^{-1}	300 fb^{-1}	$\longrightarrow$	3000 fb^{-1}
LHCb	3 fb^{-1}	9 fb^{-1}	23 fb^{-1}	50 fb^{-1}	*300 fb^{-1}

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

- A first LHCb upgrade is ready to start next year to raise the instantaneous luminosity to $2x10^{33}$ $cm^{-2}s^{-1}$, whereas the HL ATLAS and CMS upgrades will come later in Run 4
- LHCb has submitted an Expression of Interest for a further upgrade during LS4 to reach $2x10^{34}$ $cm^{-2}s^{-1}$ and a Framework Technical Design Report is due to the LHCC in 2021



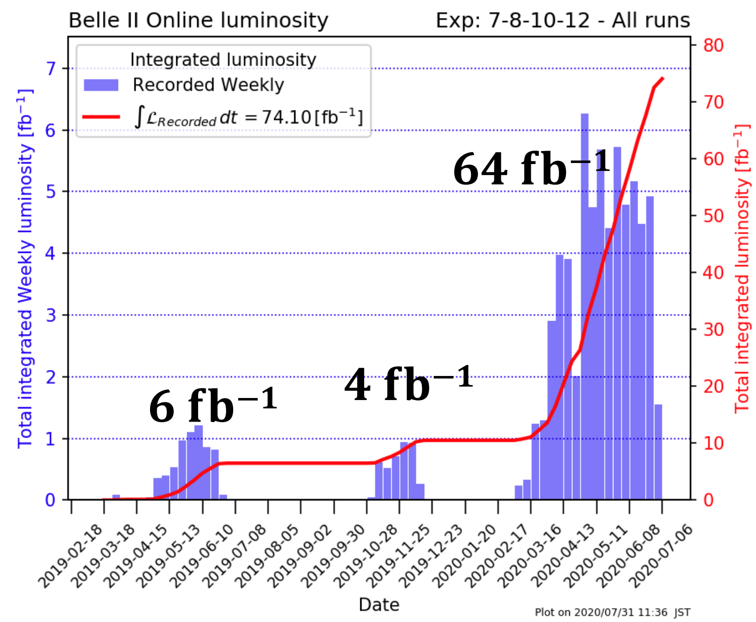
CERN-LHCC-2017-003

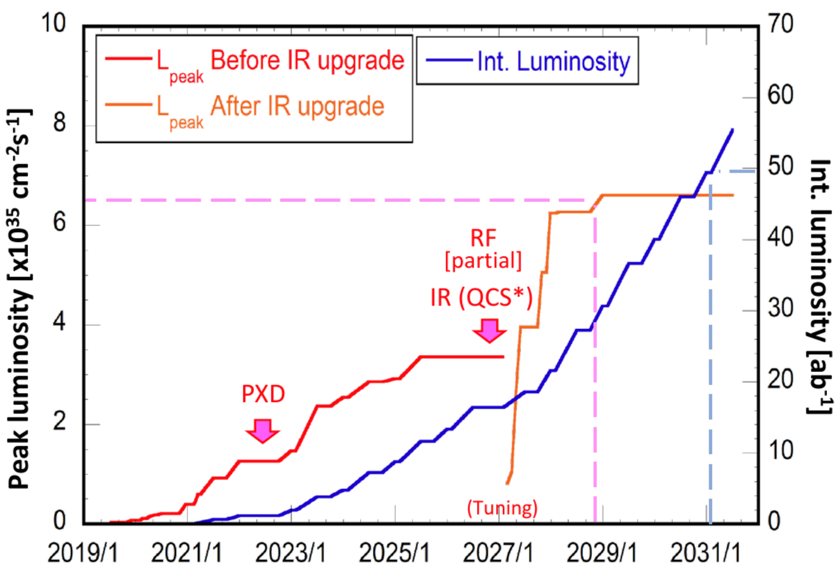


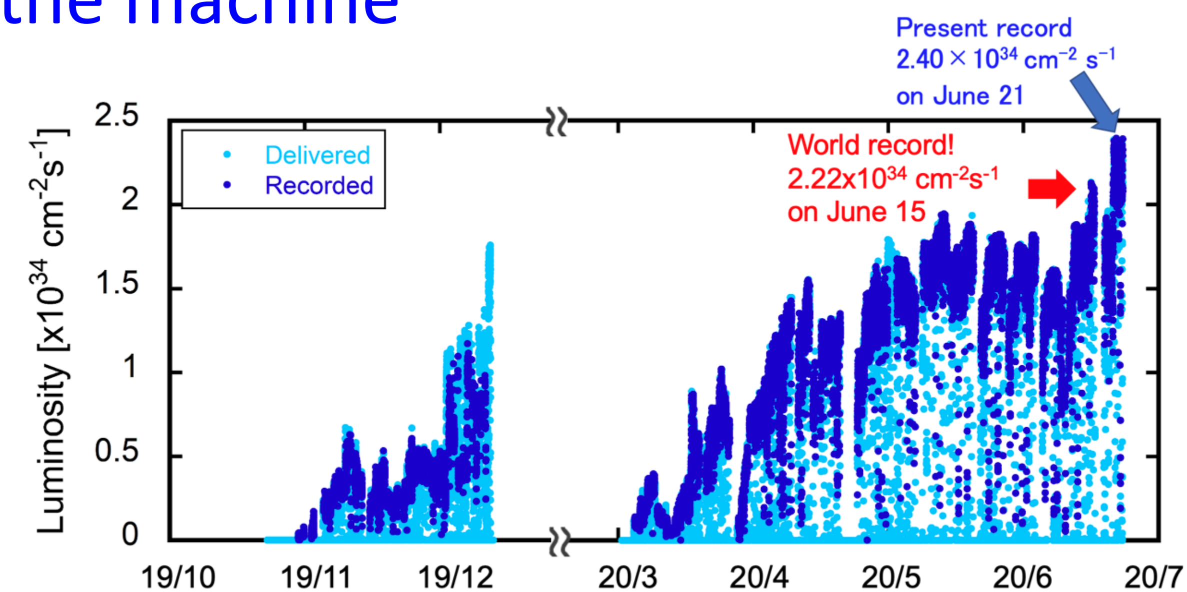
CERN-LHCC-2018-027
arXiv:1808.08865

Belle II taking first data

- Exciting prospects from the SuperKEKB machine and new Belle-II detector
- An integrated luminosity of 50 ab^{-1} will be collected by the end of the decade
- First measurements so far show that the detector works beautifully
  → the critical path is on the machine

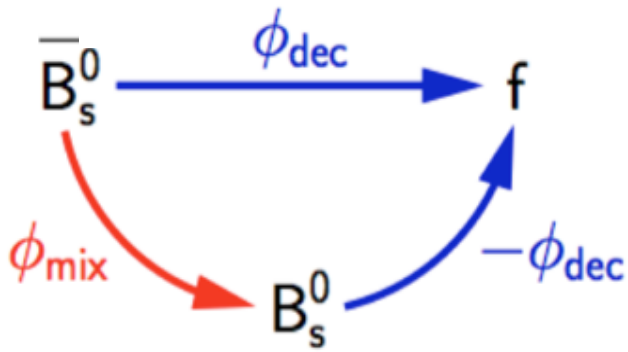




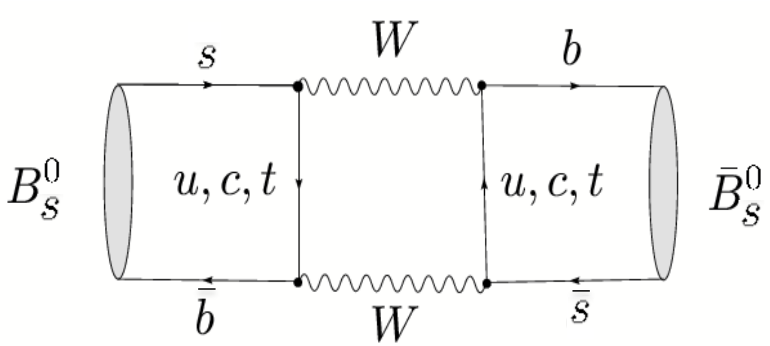


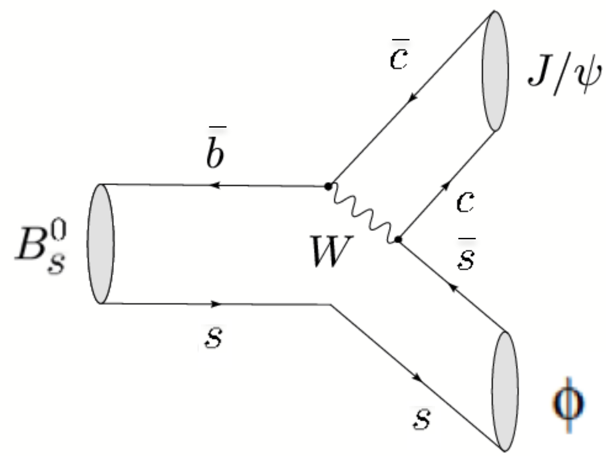
Selected results
CP violation and CKM

Measurement of ϕ_s



- Golden mode $B_s \rightarrow J/\psi\phi$ is the B_s analogue to $B^0 \rightarrow J/\psi K_S$
- Interference between B_s mixing and decay graphs

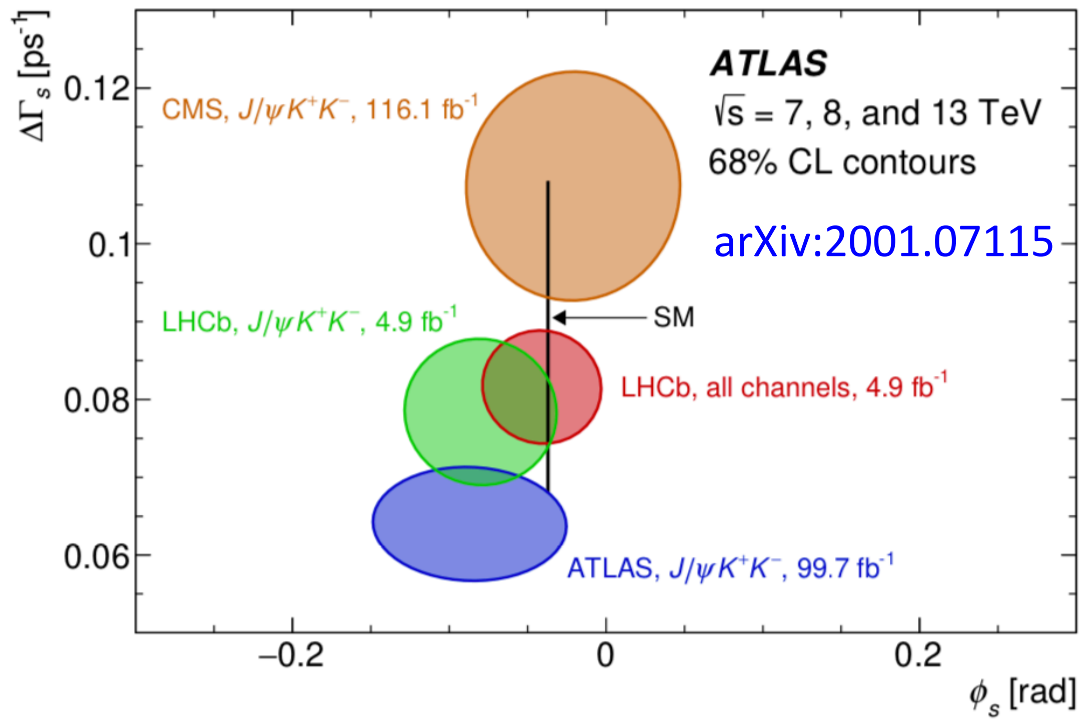




- One measures the phase-difference ϕ_s between the two diagrams, precisely predicted in the SM to be $\phi_s = -2\lambda^2\eta \simeq -37$ mrad → very small, can receive sizeable contributions from new physics

Measurement of ϕ_s

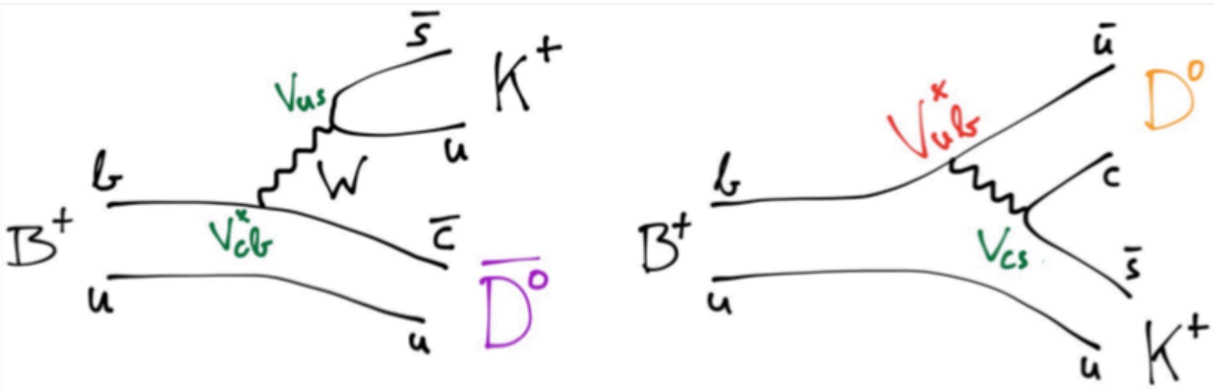
- ϕ_s precision mostly driven by LHCb, ATLAS and CMS
- Latest HFLAV world average
  - $\phi_s = -41 \pm 25$ mrad
  - Well compatible with the SM at the present level of precision

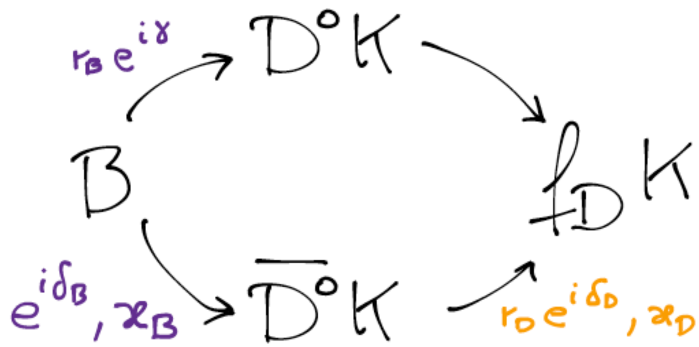


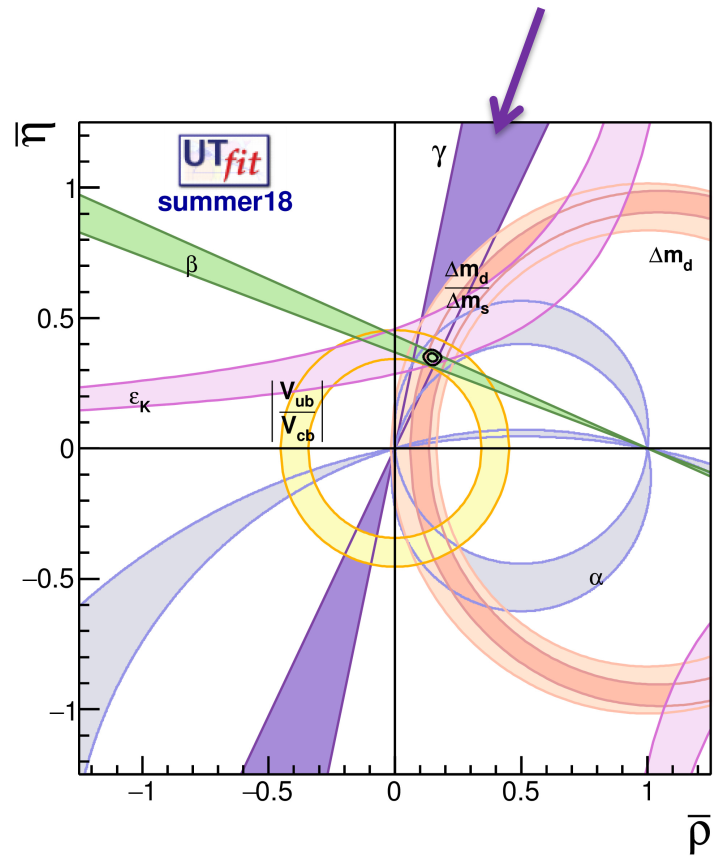
- Starting to approach the sensitivity needed to observe a nonzero SM value
- Tensions between the various measurements of Γ_s and $\Delta\Gamma_s$ call for a clarification of the experimental picture

Measurement of γ

- γ is the least known angle of the unitarity triangle
- It is measured via the interference between *b*→*c* and *b*→*u* tree-level quark transitions



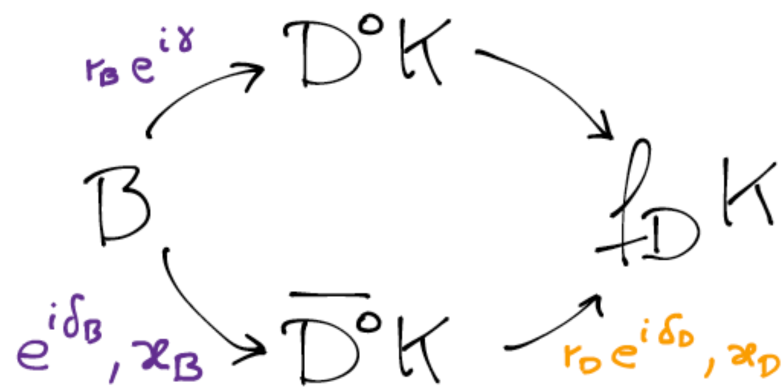




- Simple and clean theoretical interpretation, but statistically very challenging

Measurement of γ

- To achieve the interference and measure *CP* violation one needs a final state that does not distinguish between D^0 and $\bar{D}^0$



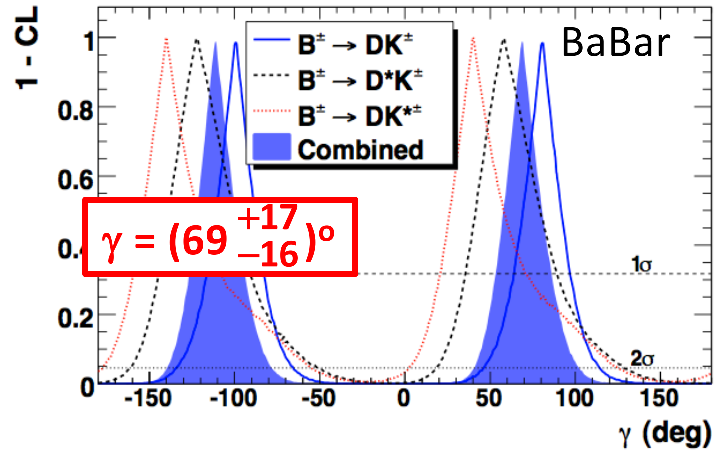
- Gronau, London, Wyler (GLW) approach
  - Use decays to *CP* eigenstates like $D^0 \rightarrow K^+K^-$ or $D^0 \rightarrow \pi^+\pi^-$
- Atwood, Dunietz, Soni (ADS) approach
  - Use decays to flavour-specific final states accessible to both D^0 and $\bar{D}^0$, e.g. $D^0 \rightarrow K^+\pi^-$ and $D^0 \rightarrow K^-\pi^+$
- Giri, Grossman, Soffer, Zupan (GGSZ) approach
  - Use three-body decay like $D^0 \rightarrow K_S\pi^+\pi^-$ → requires Dalitz analysis

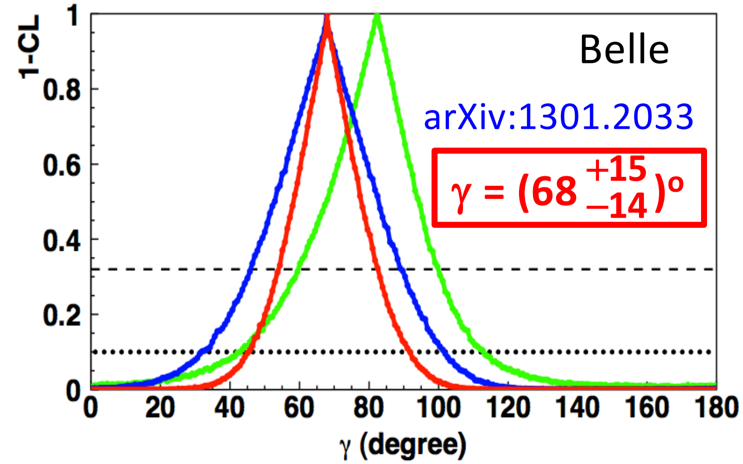
Measurement of γ

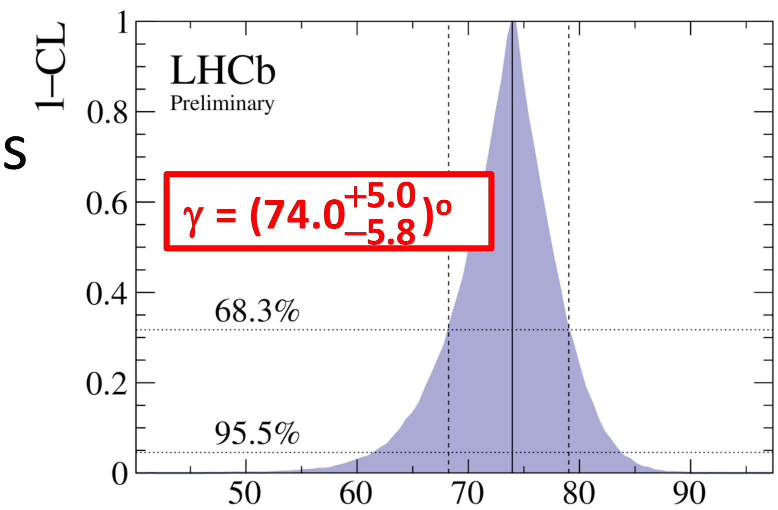
B decay	D decay	Method
$B^+ \to Dh^+$	$D \to h^+h^-$	GLW/ADS
$B^+ \to Dh^+$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS
$B^+ \to Dh^+$	$D \to h^+h^-\pi^0$	GLW/ADS
$B^+ \to DK^+$	$D \to K^0_S h^+h^-$	GGSZ
$B^+ \to DK^+$	$D \to K^0_S K^+\pi^-$	GLS
$B^+ \to Dh^+\pi^-\pi^+$	$D \to h^+h^-$	GLW/ADS
$B^0 \to DK^{*0}$	$D \to K^+\pi^-$	ADS
$B^0 \to DK^+\pi^-$	$D \to h^+h^-$	GLW-Dalitz
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	GGSZ
$B^0_s \to D^\mp_s K^\pm$	$D^+_s \to h^+h^-\pi^+$	TD

- A plethora of independent measurements exploiting different methods and decays
- LHCb significantly more precise than previous results from the *B*-factories and undergoing continuous improvements

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







LHCb-CONF-2018-002

Most precise measurement of γ by LHCb

- Recent measurement of γ with $B^{\pm} \to D^0 K^{\pm}$ and $B^{\pm} \to D^0 \pi^{\pm}$ (with $D^0 \to K^0_S \pi^+ \pi^-$ or $D^0 \to K^0_S K^+ K^-$) using model-independent approach
  - Full LHCb statistics of 9 fb^{-1} integrated in Run 1 and 2
  - Relevant reduction of systematic uncertainties with updated strong-phase inputs from BESIII, arXiv:2003.00091 → The impact of the new inputs from the BESIII collaboration has lead to the strong-phase related uncertainty on γ to be approximately 1°
- The best single measurement of γ to date!

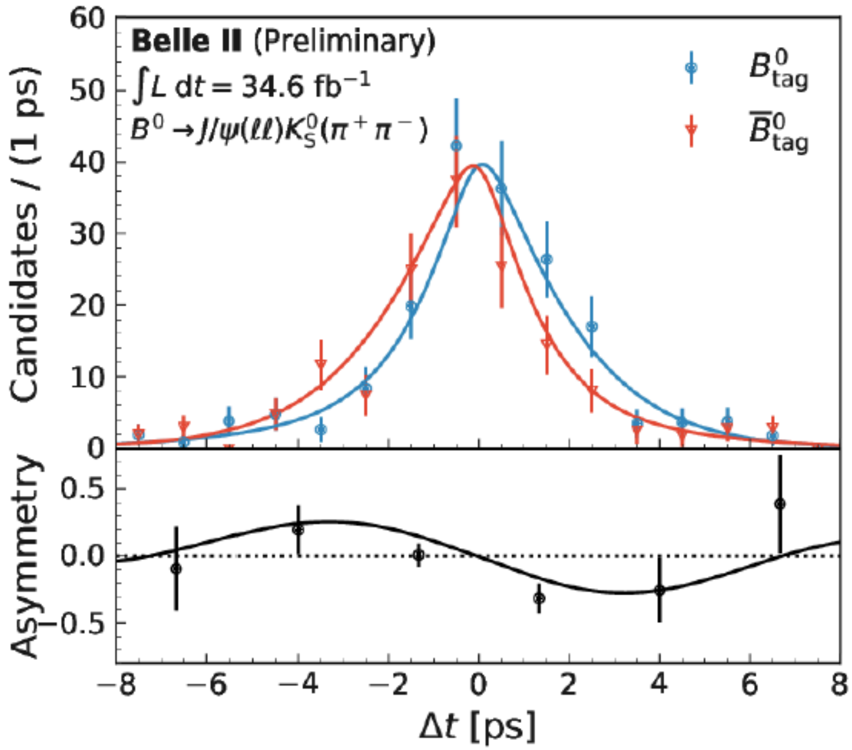
2011 -2018: Preliminary

$$\gamma = (69 \pm 5)^{\circ}$$

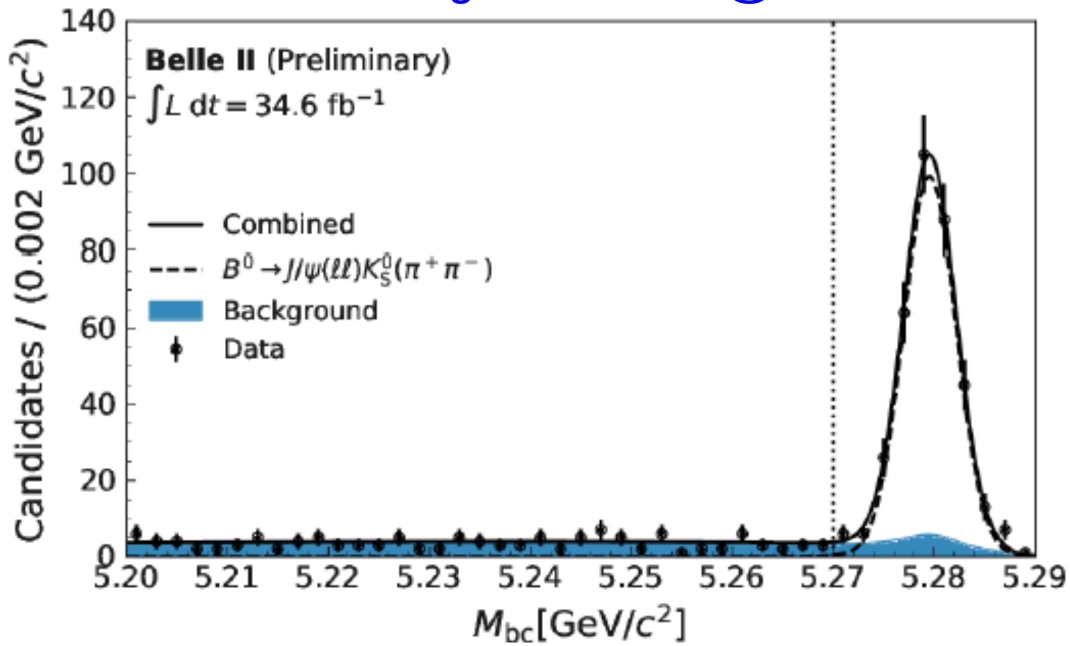
LHCb-CONF-2020-001

- LHCb is on track to surpass the 4° target with full Run 1+2 statistics

Belle II warming up



See e.g. Doris Kim @ ICHEP 2020



- A déjà vu: early measurement of sin2β with $B^0 \to J/\psi K_S$

$$\text{Belle II:}\quad S_f \approx \sin 2\phi_1 = 0.55 \pm 0.21 \pm 0.04.$$

$$\text{W. A.:}\quad S_f \approx 0.691 \pm 0.017.$$

- Still with very limited luminosity, but when the machine will ramp up the experiment has shown to be ready and chase the data very quickly

Δm_d and Δm_s

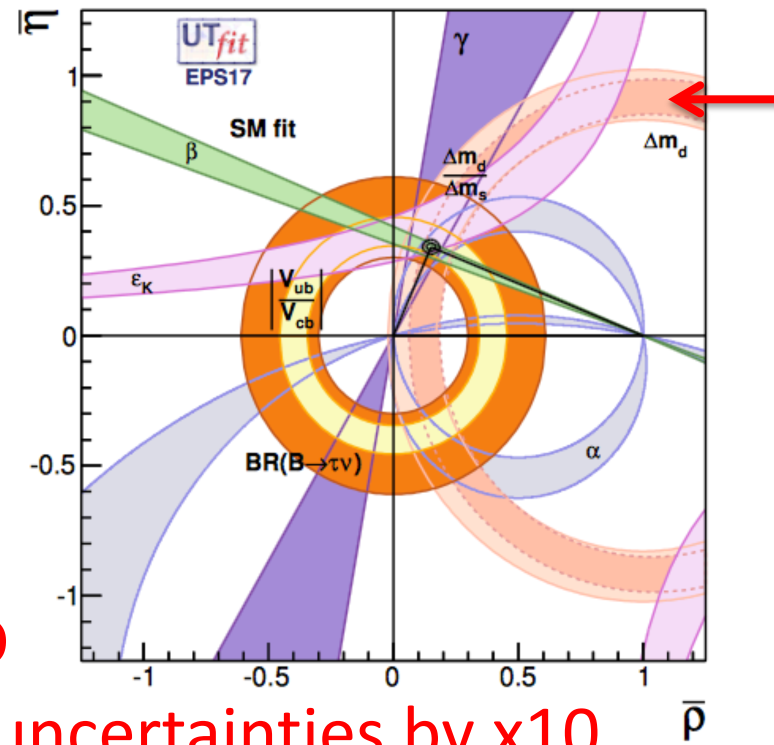
- Experimental precision has reached a remarkable level at the per mille level, dominated by LHCb
  - $\Delta m_d = 0.5065 \pm 0.0019$ ps^{-1}
  - $\Delta m_s = 17.757 \pm 0.021$ ps^{-1}
- However, the interpretation requires inputs from LQCD

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

~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%



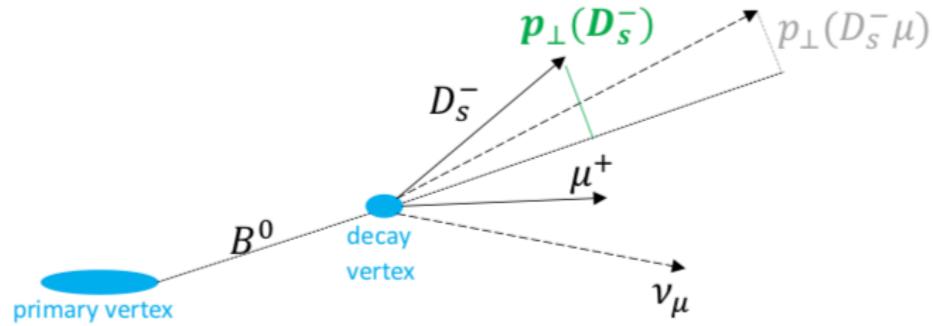
- The quest for precision with these constraints is now on LQCD
  - Need to sustain efforts from the LQCD community to reduce the theoretical uncertainties by x10

Also measure $|V_{cb}|$ at a hadron collider!

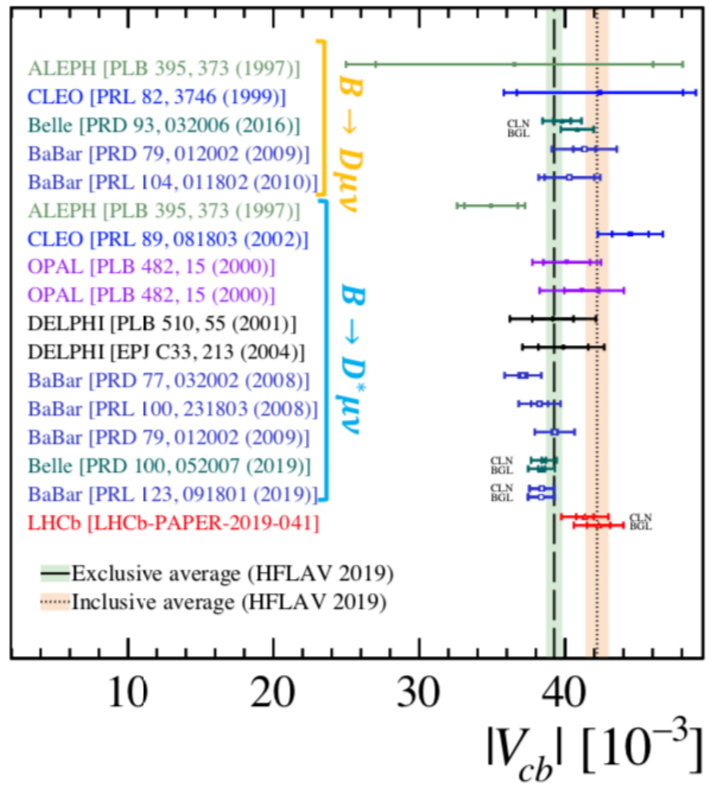
PRD 101 (2020) 072004

- First measurement of $|V_{cb}|$ by LHCb using $B_s \to D_s\mu\nu$ and $B_s \to D_s^*\mu\nu$
  - Obtained from measurement of decay rate as a function of the recoil $\boldsymbol{w}$
  - Exploit $\boldsymbol{p_\perp(D_s)}$ which is fully reconstructed and highly correlated with $\boldsymbol{w}$

$$w = (m_B^2 + m_{D^{(*)}}^2 - q^2)/(2m_B m_{D^{(*)}})$$



$$|V_{cb}|_{\rm CLN} = (41.4 \pm 0.6\,({\rm stat}) \pm 0.9\,({\rm syst}) \pm 1.2\,({\rm ext})) \times 10^{-3}$$
$$|V_{cb}|_{\rm BGL} = (42.3 \pm 0.8\,({\rm stat}) \pm 0.9\,({\rm syst}) \pm 1.2\,({\rm ext})) \times 10^{-3}$$



Modest dependence on the choice of form-factor parameterisation (CLN or BGL)

Observation of *CP* violation in charm

Phys. Rev. Lett. 122 (2019) 211803

$$\Delta A_{CP} \equiv A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)$$

$$A_{\text{raw}}(f) = \frac{N(D^0 \to f) - N(\bar{D}^0 \to f)}{N(D^0 \to f) + N(\bar{D}^0 \to f)}$$

$D^{*+} \to D^0(\to K^+K^-)\pi_s^+$ | $D^{*+} \to D^0(\to \pi^+\pi^-)\pi_s^+$

$$A_{\text{raw}}(f) \simeq A_{CP}(f) + A_{\text{D}}(f) + A_{\text{D}}(\pi_s) + A_{\text{P}}(D^{*+})$$

- $A_{CP}(f)$: Physical *CP* asymmetry
- $A_{\text{D}}(f)$: D^0 detection asymmetry ➔ equal to zero, since K^-K^+ and $\pi^-\pi^+$ are symmetric final states
- $A_{\text{D}}(\pi_s)$: π_s detection asymmetry
- $A_{\text{P}}(D^{*+})$: D^* production asymmetry

π_s detection asymmetry and D^* production asymmetry → Independent on the final state

- If the kinematics of the D^{*+} and π_s for the two decay modes are equal

$$\Rightarrow A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) = A_{\text{raw}}(K^-K^+) - A_{\text{raw}}(\pi^-\pi^+)$$

- Production and detection asymmetries are cancelled
- Very robust measurement against systematic uncertainties

Results for ΔA_{CP}

Phys. Rev. Lett. 122 (2019) 211803

- Run-2 results well compatible with previous LHCb results and world average

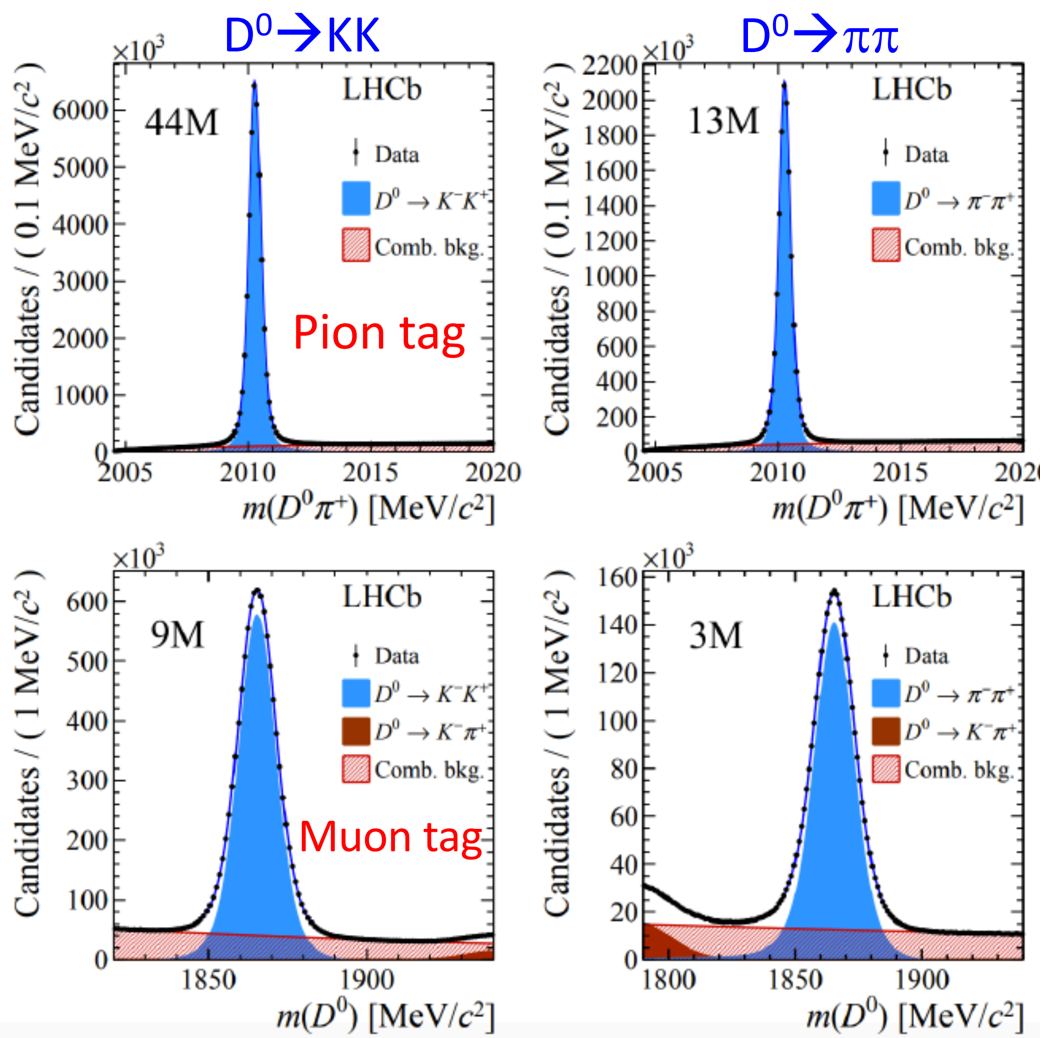
$$\Delta A_{CP}^{\pi\text{-tagged}} = [-18.2 \pm 3.2\,(\text{stat.}) \pm 0.9\,(\text{syst.})] \times 10^{-4}$$

$$\Delta A_{CP}^{\mu\text{-tagged}} = [-9 \pm 8\,(\text{stat.}) \pm 5\,(\text{syst.})] \times 10^{-4}$$

- Combination of Run-1 and Run-2 data gives

$$\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4}$$

- CP violation observed at 5.3σ



ΔA_{CP}: comparison with the SM

- The result is roughly consistent with SM expectations, which lie in the range $10^{-4} - 10^{-3}$
  - Hence roughly compatible with the SM, which is however way more uncertain than data
- There are theoretical speculations that there might be new physics in the up-quark sector at work
  - Further measurements with charmed particles, along with possible theoretical improvements, will help clarify the physics picture
- Furthermore, with mixing-induced CPV measurements, such as A_Γ from two-body decays and from $D^0 \rightarrow K_S\pi\pi$, WS/RS(t) in $D \rightarrow K\pi$, etc., there's still plenty of room before reaching the precision to measure SM predictions, that are generally more accurate than those for direct CPV

Selected results

Rare decays and *B*-physics anomalies

Why studying rare decays

- Decays characterised by very small branching fractions in the Standard Model are excellent laboratories to look for new-physics effects

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

- For example, flavour-changing neutral-current (FCNC) processes cannot proceed at tree level in the SM and so need higher order diagrams → strong suppression
  - And further suppressions may arise from additional mechanisms

Measurement of $B \to \mu^+\mu^-$ decays

- Highly suppressed in the SM
  - FCNC- and helicity-suppressed, proceed via *Z* penguin and *W* box
- The helicity suppression of vector(-axial) terms make these decays particularly sensitive to new physics (pseudo-)scalar contributions, such as extra Higgs doublets, which can raise the branching fraction with respect to the Standard Model
- Branching fractions for B^0 and B_s decays to two muons are precisely predicted in the SM

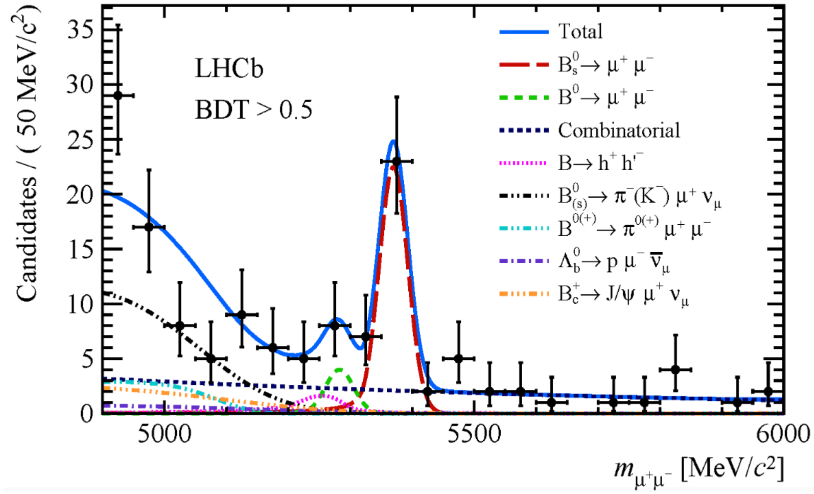
$$\begin{aligned} \mathcal{B}(B_s^0 \to \mu^+\mu^-) &= (3.66 \pm 0.14) \times 10^{-9} \\ \mathcal{B}(B^0 \to \mu^+\mu^-) &= (1.03 \pm 0.05) \times 10^{-10} \end{aligned}$$

JHEP 10 (2019) 232

Measurement of $B \rightarrow \mu^+\mu^-$ decays

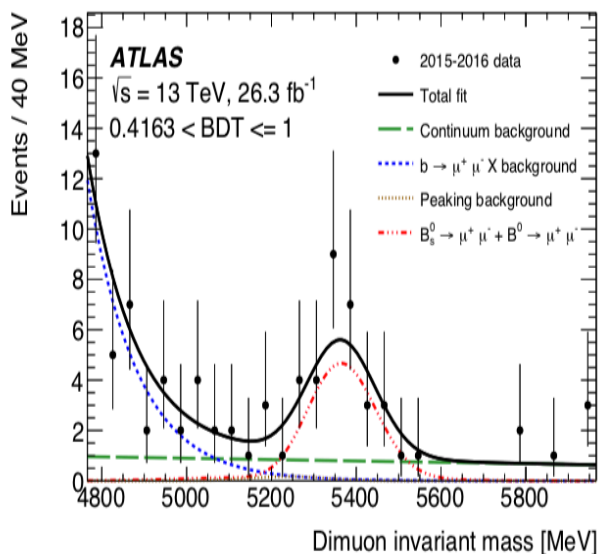
- Now measured by ATLAS, CMS and LHCb using Run-2 data
- Combination of the three results recently done

Phys. Rev. Lett. 118 (2017) 191801



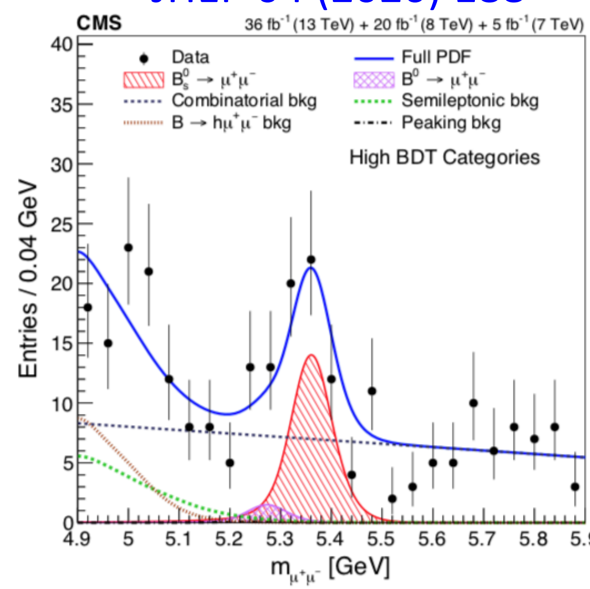
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(3.0 \pm 0.6\,^{+0.3}_{-0.2}\right) \times 10^{-9},$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \left(1.5\,^{+1.2}_{-1.0}\,^{+0.2}_{-0.1}\right) \times 10^{-10},$$

JHEP 04 (2019) 098



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(2.8\,^{+0.8}_{-0.7}\right) \times 10^{-9},$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (-1.9 \pm 1.6) \times 10^{-10},$$

JHEP 04 (2020) 188

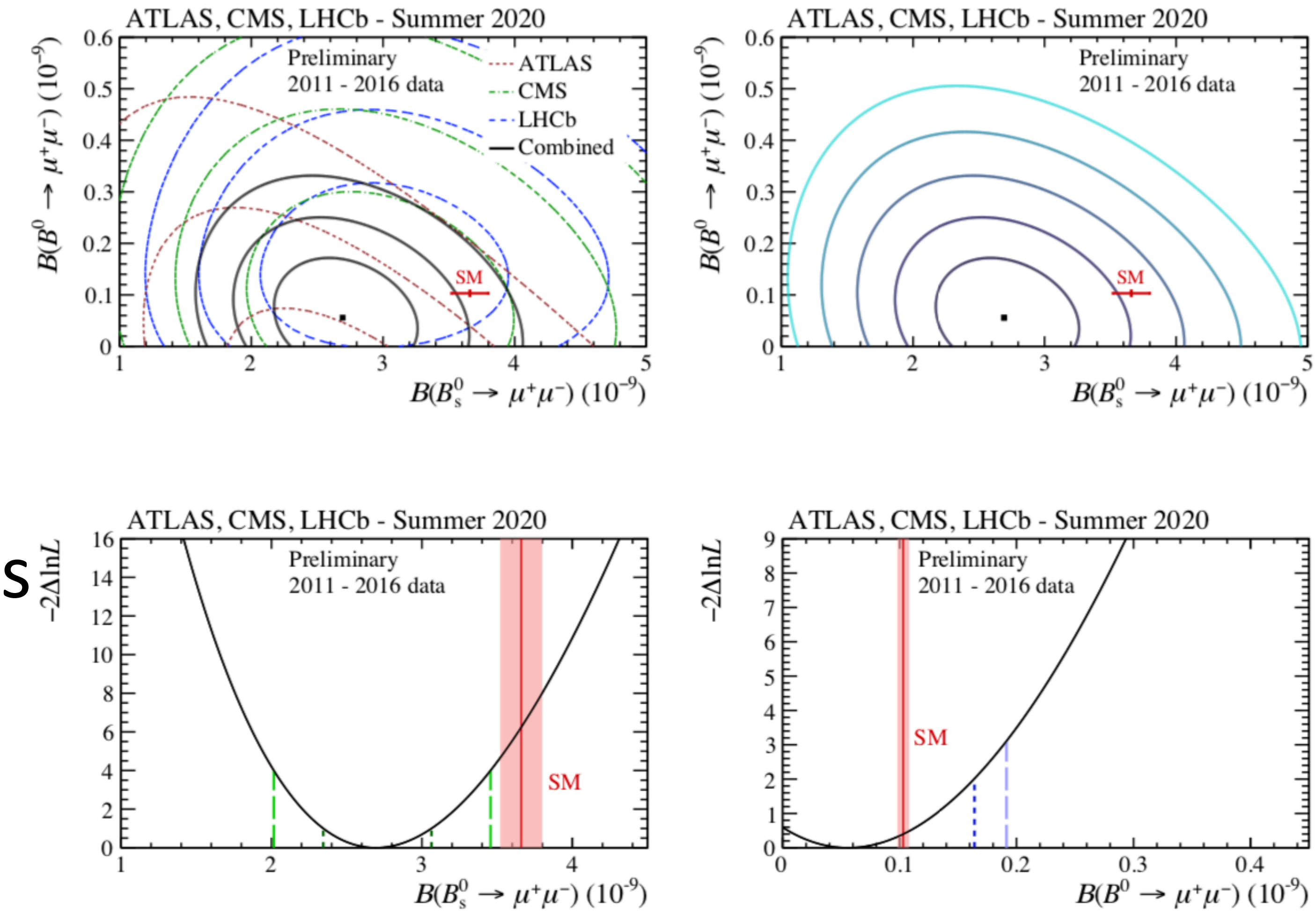


$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left[2.9\,^{+0.7}_{-0.6}(\text{exp}) \pm 0.2(\text{frag})\right] \times 10^{-9},$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \left(0.8\,^{+1.4}_{-1.3}\right) \times 10^{-10},$$

Combination of BR($B \to \mu^+\mu^-$)

LHCB-CONF-2020-002
CMS PAS BPH-20-003
ATLAS-CONF-2020-049

- Good agreement between the results of the three experiments and also with the Standard Model



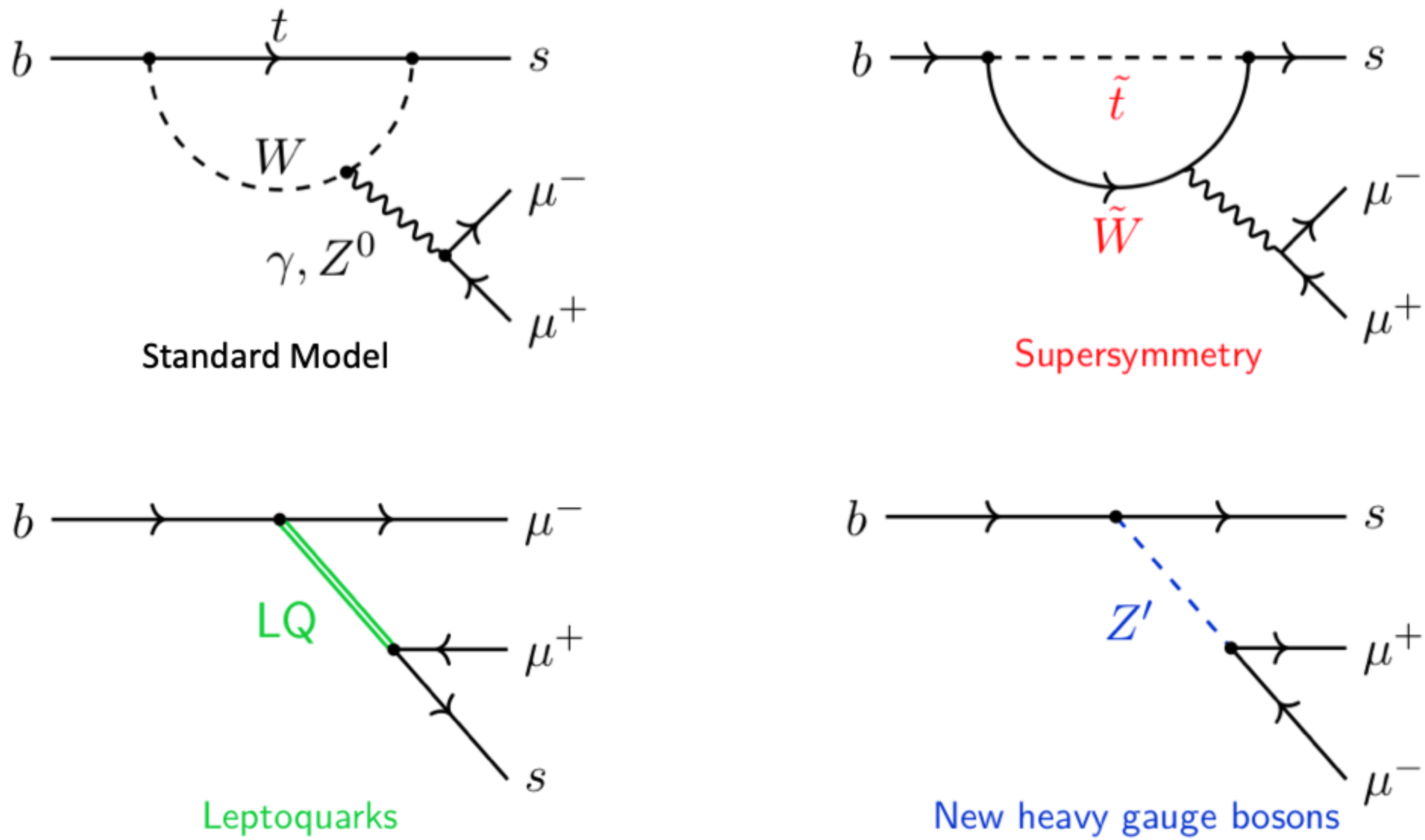
New LHC average

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.69\,^{+0.37}_{-0.35}) \times 10^{-9}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.6 \times 10^{-10} \text{ at } 90\% \text{ CL}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.9 \times 10^{-10} \text{ at } 95\% \text{ CL}$$

$b \rightarrow s\ell^+\ell^-$ transitions

- $B \rightarrow \mu^+\mu^-$ decays belong to a more general family of quark-level diagrams which includes other relevant decays like $B \rightarrow K\mu^+\mu^-$



Measurements that can be done with $b \to s\ell^+\ell^-$ channels

- Lepton-flavour universality (LFU) tests
  - checking that electrons and muons exhibit the same couplings, as expected in the Standard Model
- Differential branching fractions as a function of the invariant mass of the lepton pair, q^2
- Full decay rate including angular variables

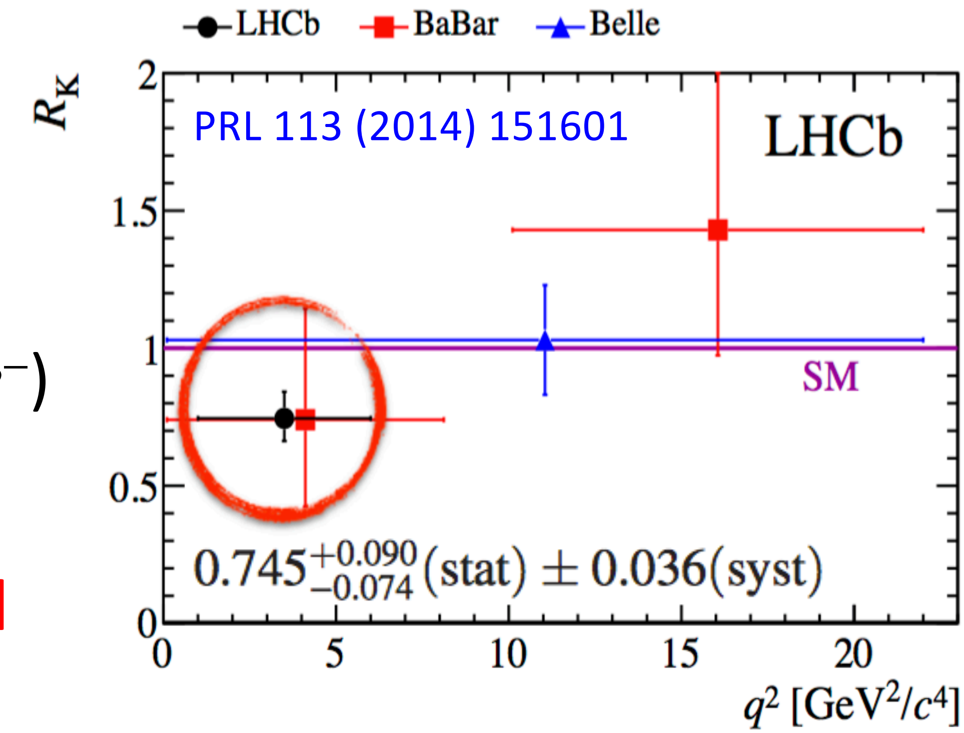
LFU tests in $b \to s\ell^+\ell^-$ transitions

- Initially measured with the ratios

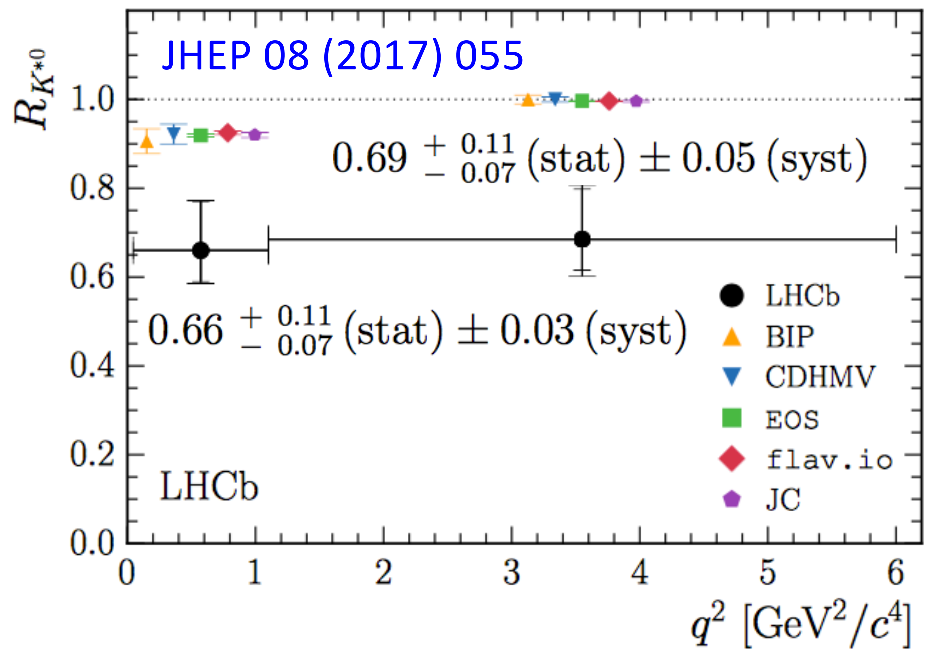
  $R_K = \mathfrak{B}(B^+ \to K^+\mu^+\mu^-) \,/\, \mathfrak{B}(B^+ \to K^+e^+e^-)$

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

- Theoretically very clean
  - Observation of non-LFU would be a clear sign of new physics



- 3σ-ish level from the SM triggered wide interest on the subject
- Updates with Run-2 as well as other new measurements with different decay modes

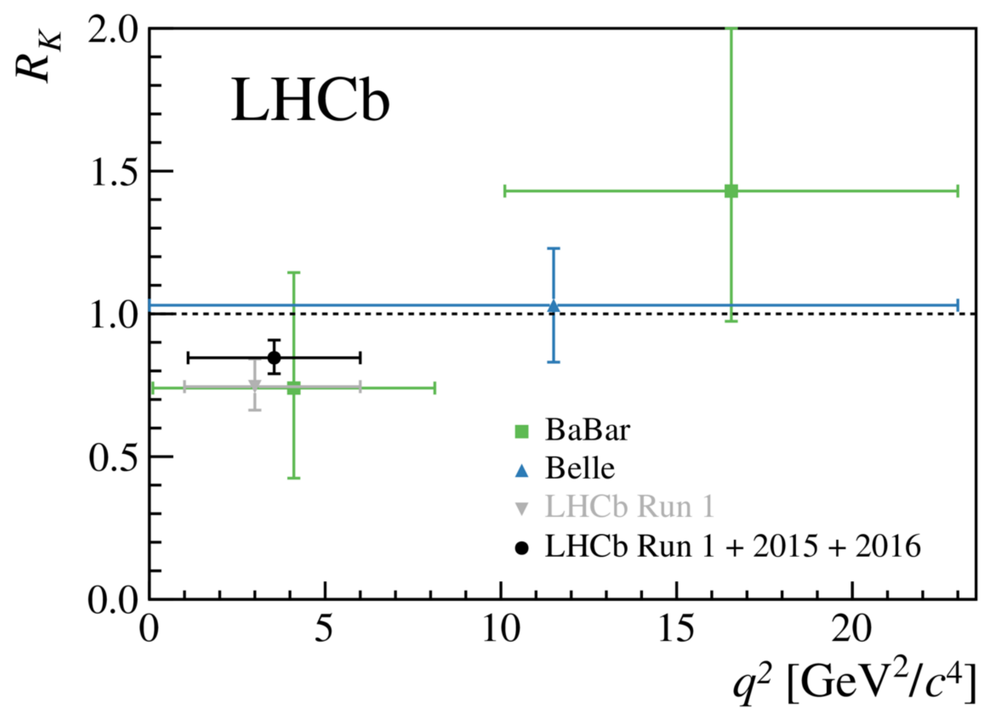


LFU tests in $b \rightarrow s\ell^+\ell^-$ transitions

- Update of the R_K measurement by LHCb in the low dilepton mass-squared range last year
  - Statistics of previous measurement doubled
  - New result: $R_K = 0.846\,^{+0.060}_{-0.054}\,^{+0.016}_{-0.014}$
- Situation practically unchanged after the new measurement
  - Reduced uncertainty but central value closer to the SM
- Outlook
  - Inclusion of 2017 and 2018 data will further double statistics
  - More channels in the loop
    - R_{K^*} but also B_s and Λ_b channels

Phys. Rev. Lett. 122 (2019) 191801

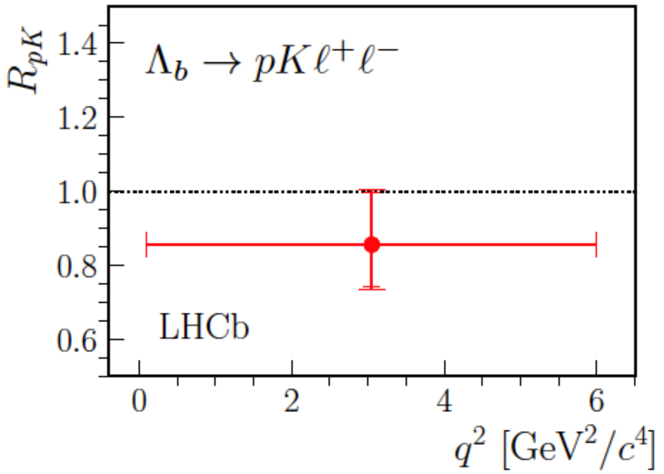
2.5σ from the SM



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

- Now also with $\Lambda_b \to pK\ell^+\ell^-$ decays!

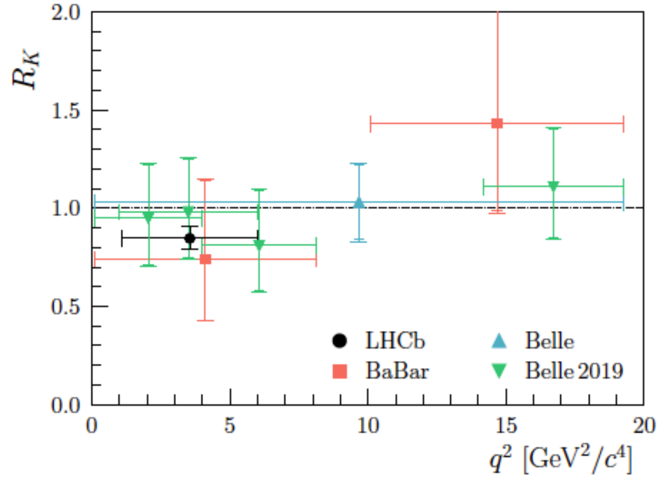
JHEP 05 (2020) 040



$$R_{pK} = 0.86^{+0.14}_{-0.11} \pm 0.05$$

$0.1 < q^2 < 6$ GeV²

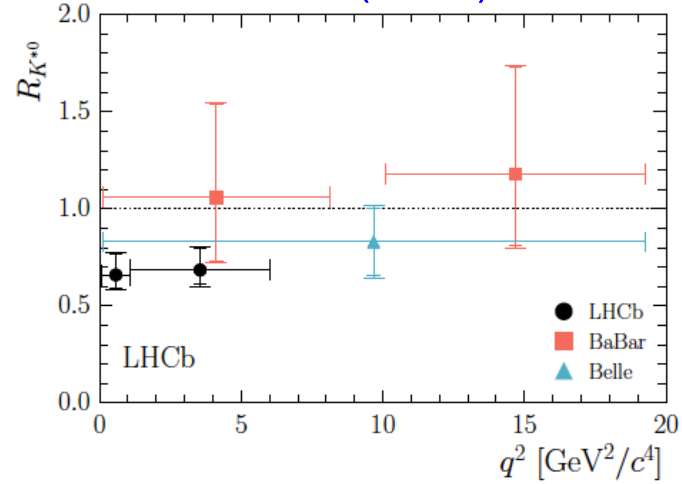
PRL 122 (2019) 191801



$$R_K = 0.846^{+0.060+0.016}_{-0.054-0.014}$$

$1.1 < q^2 < 6$ GeV²

JHEP 08 (2017) 055



$$R_{K^*} = 0.69^{+0.11}_{-0.07} \pm 0.05$$

$1.1 < q^2 < 6$ GeV²

- Is there a real pattern or just weird statistical fluctuations?
- Uncertainties still large and statistically dominated

Effective field theory and $b \to s \ell^+ \ell^-$

- Effective field theory can be used to combine the all relevant observables in $b \to s \ell^+ \ell^-$ decays
  - (differential) BFs, angular observables, LFU ratios, …
- Amplitude of decay process calculated as an operator

$$A(M \to F) = \langle F | \mathcal{H}_{eff} | M \rangle = \frac{G_F}{\sqrt{2}} \sum_i V^i_{CKM} C_i(\mu) \langle F | O_i(\mu) | M \rangle$$

Hadronic Matrix Elements

Effective Hamiltonian

CKM couplings

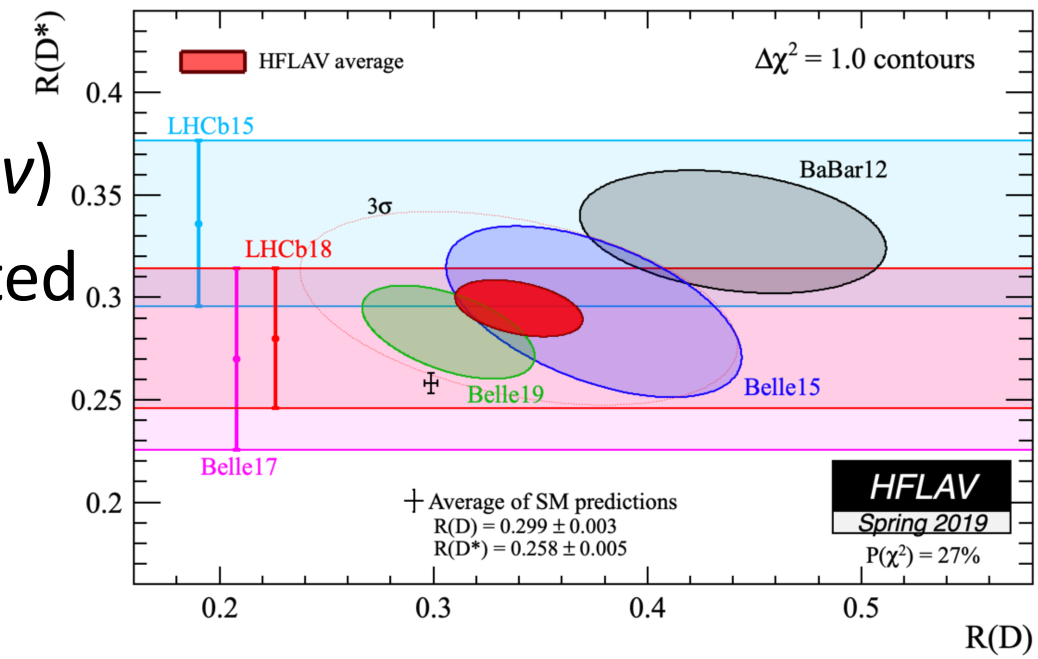
Wilson coefficients (μ = scale)

- Global fits of Wilson coefficients performed by some theory groups get an overall picture pointing to possible hints of new physics

e.g. JHEP 06 (2016) 092, EPJC 77 (2017) 377, JHEP 1801 (2018) 093

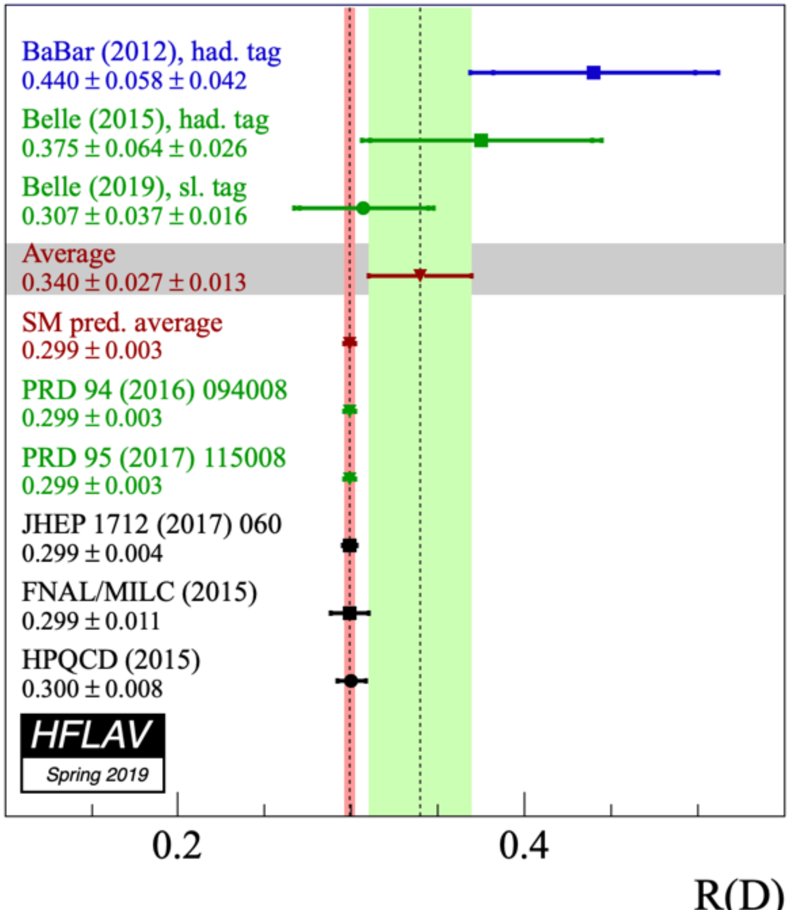
LFU tests with semitauonic decays
$B \rightarrow D^{(*)}\tau\nu$

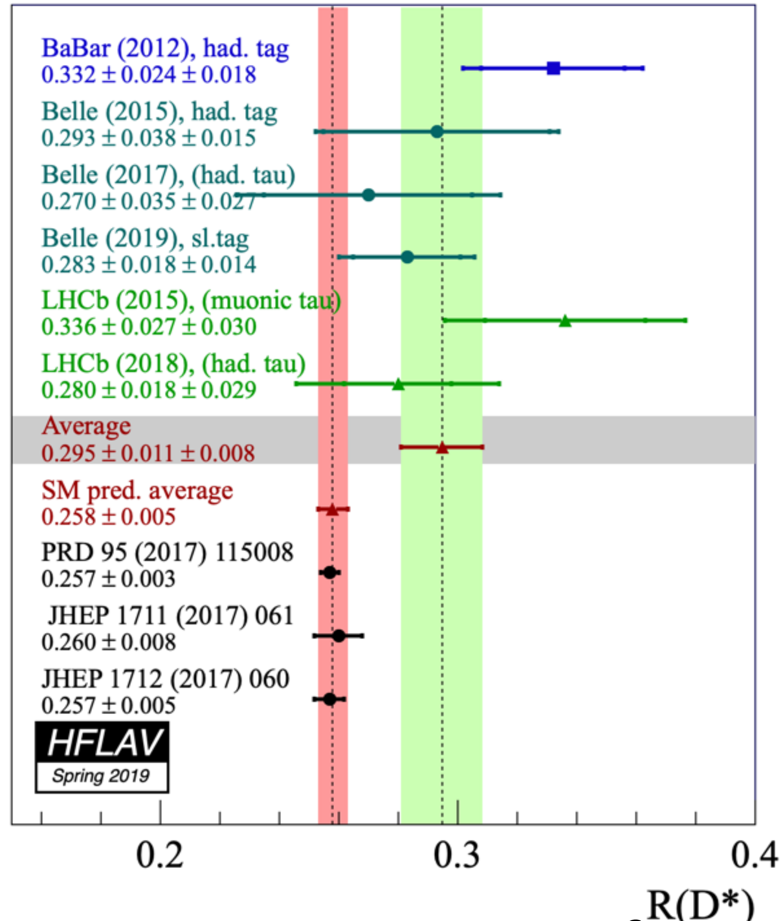
- Measure ratios like $R_D^{(*)} = \mathfrak{B}(B \rightarrow D^{(*)}\tau\nu) / \mathfrak{B}(B \rightarrow D^{(*)}\mu\nu)$
- Such ratios are precisely predicted in the SM and any significant deviation would be a clear indication of new physics



- Measurements of R_D and R_{D*} by BaBar, Belle and LHCb
  - Overall average shows a discrepancy from the SM of about 3.1σ
- Waiting for Belle II to join, LHCb can also perform measurements with other *b* hadrons
  - e.g. B_s, B_c and Λ_b decays will help better understand the global picture

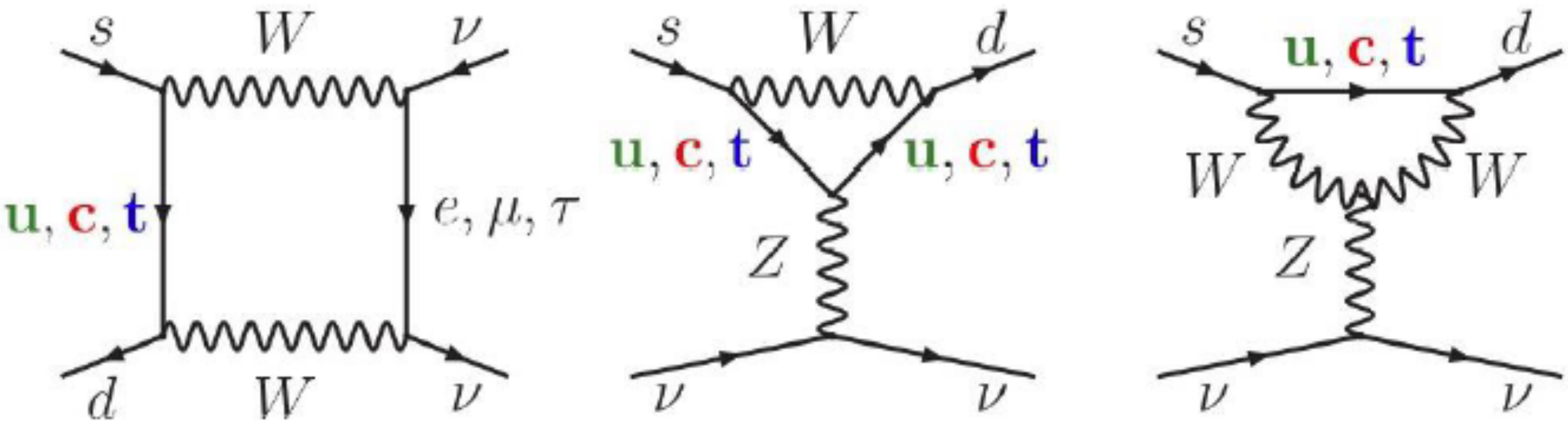
LFU tests with semitauonic decays $B \rightarrow D^{(*)} \tau \nu$





- Outlook: more data and new analyses are coming soon from LHCb and then Belle II
  - Within a few years we'll know for sure whether this is a weird fluctuation, an experimental bias or a real effect

News from NA62: $K^+ \rightarrow \pi^+ \nu\nu$



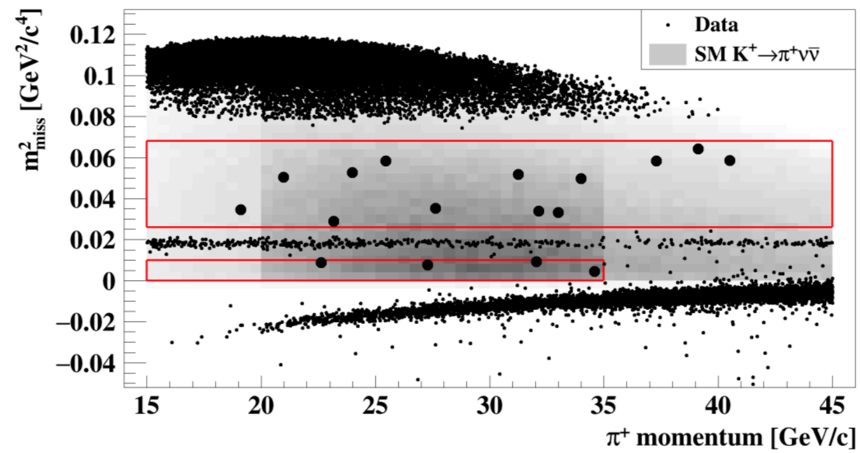
- FCNC loop processes with s→d coupling and extreme CKM suppression
- Very sensitive to new physics in loops and theoretically clean
  - SM prediction, JHEP 11 (2015) 33

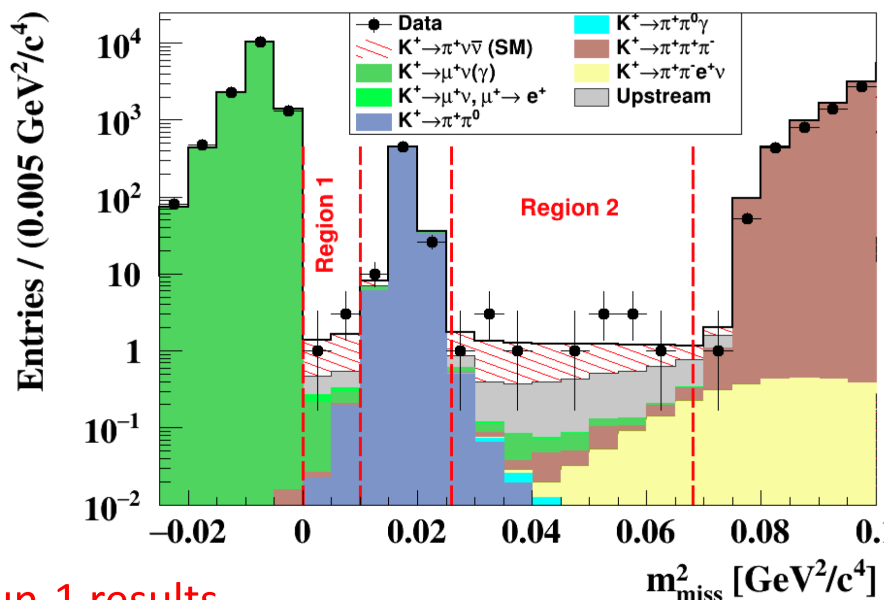
$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.39 \pm 0.30) \cdot 10^{-11} \left(\frac{|V_{cb}|}{0.0407}\right)^{2.8} \left(\frac{\gamma}{73.2^\circ}\right)^{0.74} = (8.4 \pm 1.0) \cdot 10^{-11}$$

News from NA62: $K^+ \rightarrow \pi^+\nu\nu$

See e.g. Giuseppe Ruggiero @ ICHEP 2020

- NA62 recently unblinded the 2018 dataset observing 17 events
  - Expected background: ~5.3 events
  - Expected SM signal: ~7.6 events
  - Single event sensitivity at the 10^{-11} level
  - 3.5σ evidence!
- 30% relative uncertainty
  - Looking forward to Run 2 to approach the 10% target (assuming SM)





Preliminary combination of Run-1 results

Expected background: ~7 Observed events: 20 (1 [2016], 2[2017], 17[2018])

$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = \left(11.0^{+4.0}_{-3.5}\Big|_{stat} \pm 0.3_{syst}\right) \times 10^{-11}$$

Concluding remarks

- In the current state with fundamental physics, it is necessary to have a programme as diversified as possible and maintain the broadest possible physics programme in the long term → upgrade of LHCb to further raise the luminosity in the LHC Run 5
- 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 to understand the structure of what lies beyond the Standard Model