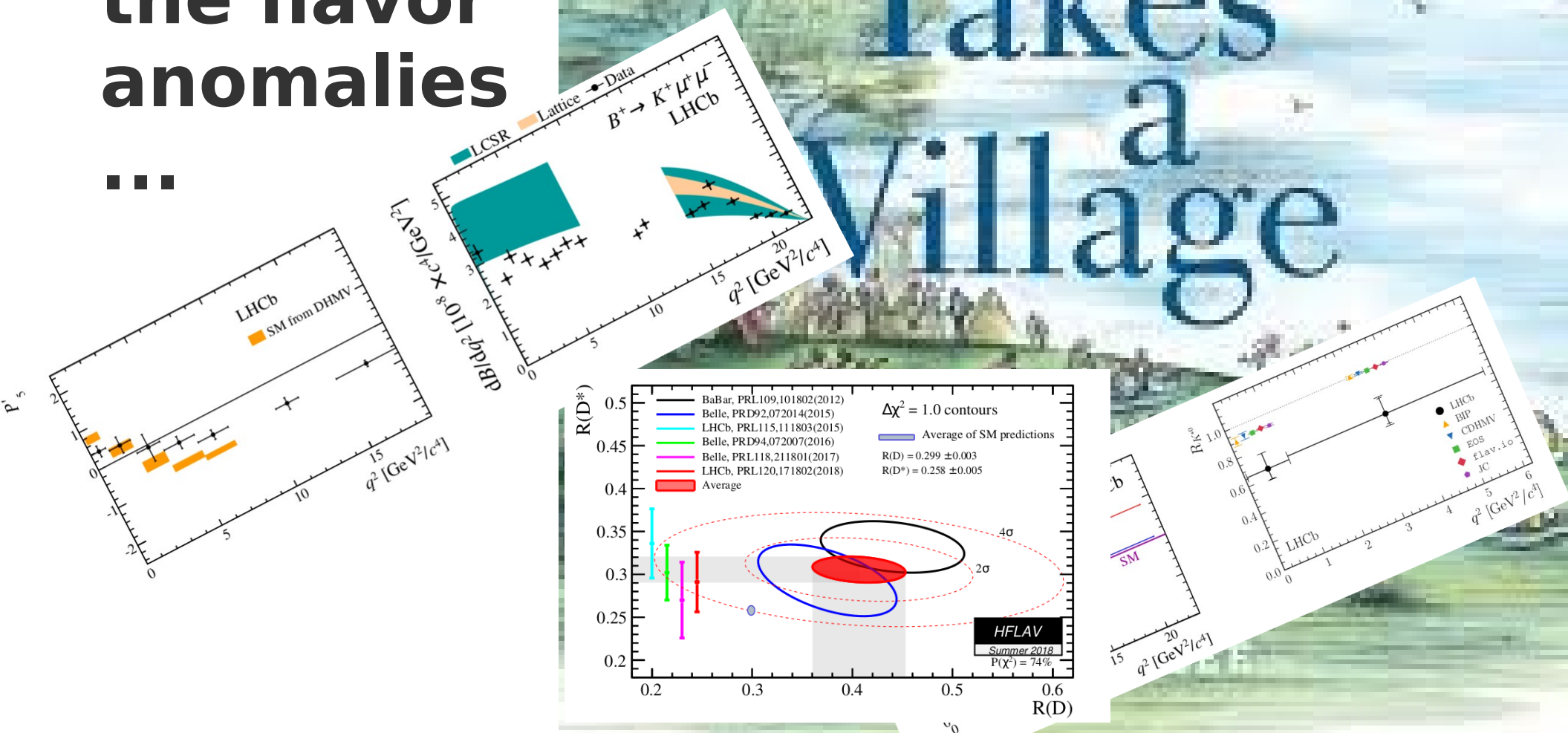# Iτ τakes a Village

Giampiero Mancinelli

(Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France)

# It takes a Village...

# ... to unveil the secrets of the flavor anomalies ...

# Why we do b→sll' to us ?

- Because the guardians of knowledge (the theorists... well, Olcyr in our case) tell us that such anomalies:

    ⇒ Imply Violation of Lepton Flavor Universality (LFU)

    ⇒ Are theoretically clean observables!

    ⇒ And... large effects in b → sμτ are predicted by (few) viable solutions.

    – Strong challenges to NP from

        - Flavor Observables, LEP/LHC high PT physics

    – Scalar and vector LQ best candidates (with predominant couplings to third generation)

        - U1 (3,1,2/3)

LHC high PT

HF

Z physics

Theory

It Takes a Village
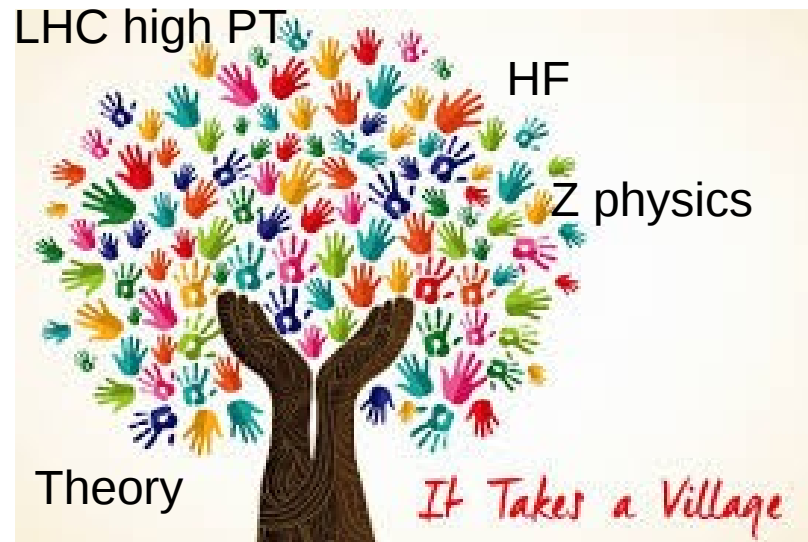
# Examples
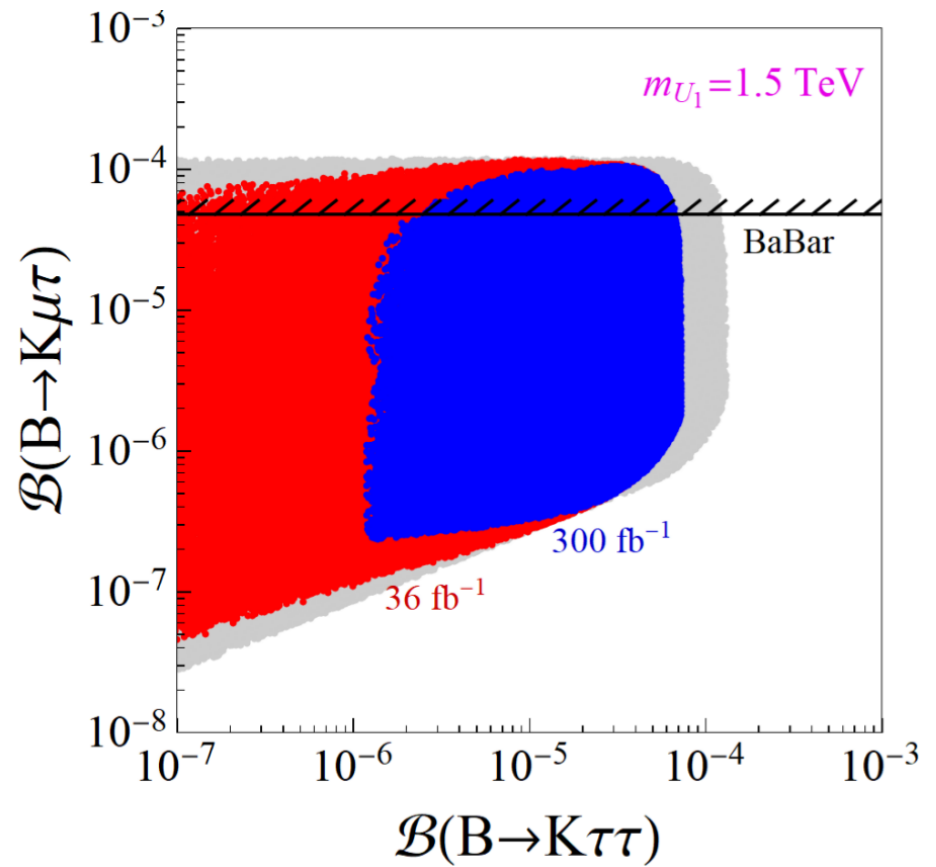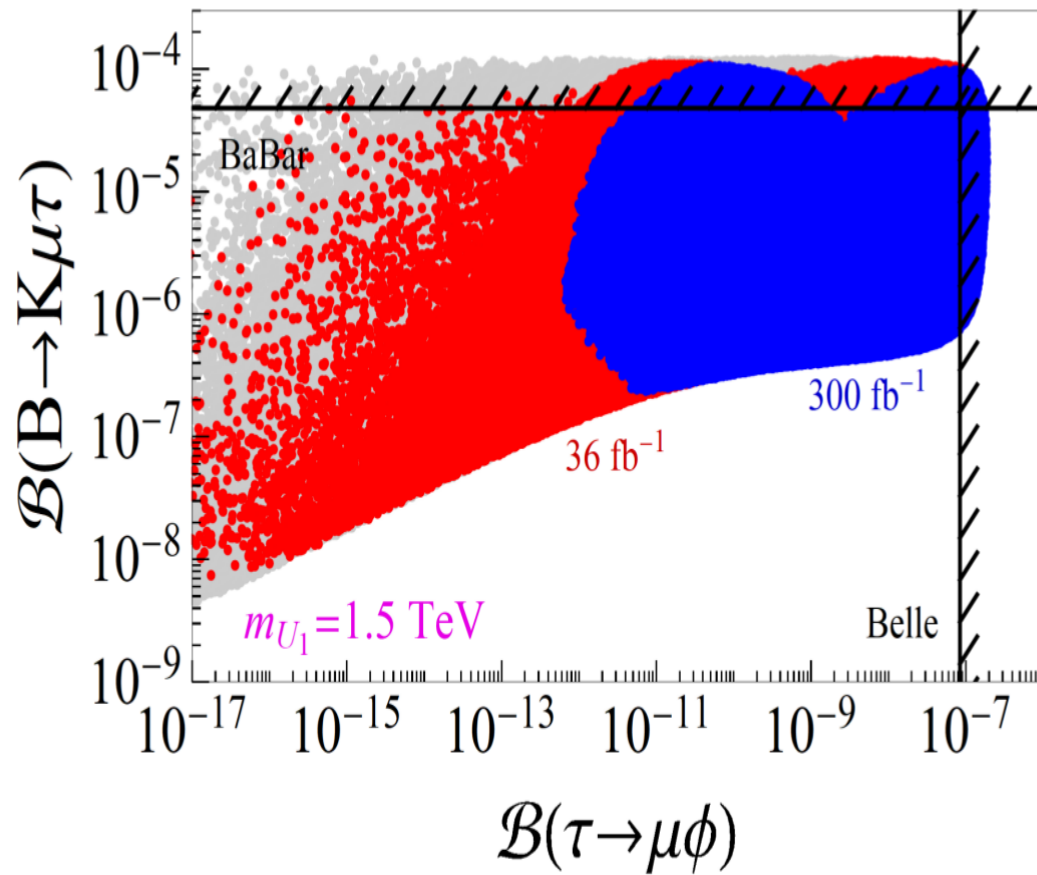


Olcyr

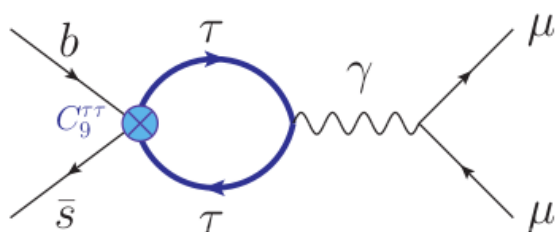# Everyone is invited to the game...

- Existing <u>direct limits</u>:

$$\mathcal{B}(B \to K\tau\tau)^{\mathrm{exp}} < 2.2 \times 10^{-3} \quad \text{[BaBar. '17]}$$

$$\mathcal{B}(B_s \to \tau\tau)^{\mathrm{exp}} < 6.8 \times 10^{-3} \quad \text{[LHCb. '17]}$$

still far from SM predictions ($\approx 10^{-7}$). Perhaps at FCC-ee?    See talk by Monteil

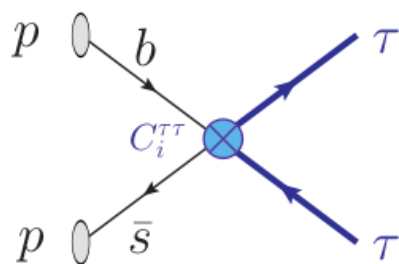- <u>New idea</u>: deformation of $B \to K\mu\mu$ $q^2$-spectrum

Olcyr



$$\mathcal{B}(B \to K\tau\tau) \lesssim 2.3 \times 10^{-3} \quad \text{[preliminary]}$$

[M. König, LHCb Implications '19]

- <u>Also promising</u>: $pp \to \tau\tau$ at high-$p_T$



$$\mathcal{B}(B \to K\tau\tau) \lesssim 1.1 \times 10^{-3} \quad (36.1 \ \mathrm{fb}^{-1})$$

$$\mathcal{B}(B \to K\tau\tau) \lesssim 1.4 \times 10^{-5} \quad (3 \ \mathrm{ab}^{-1})$$
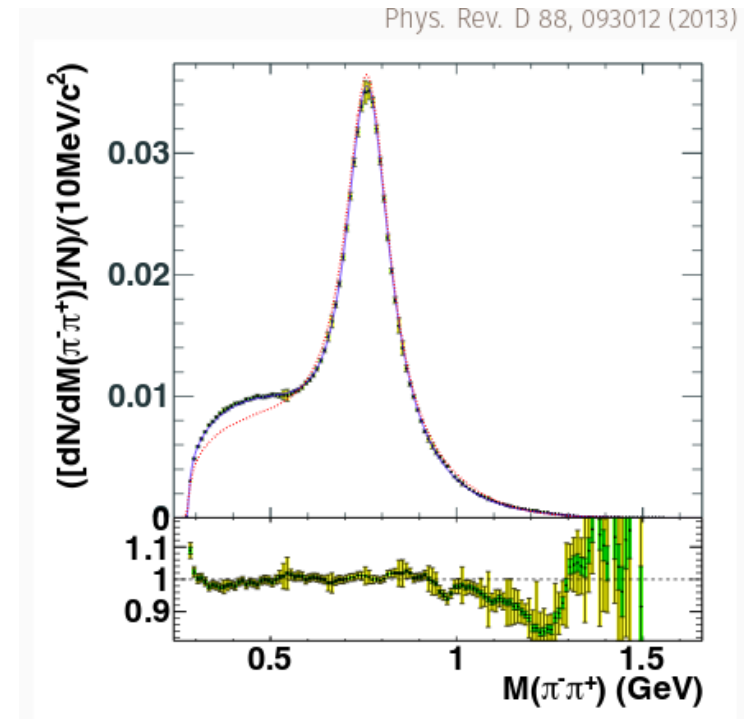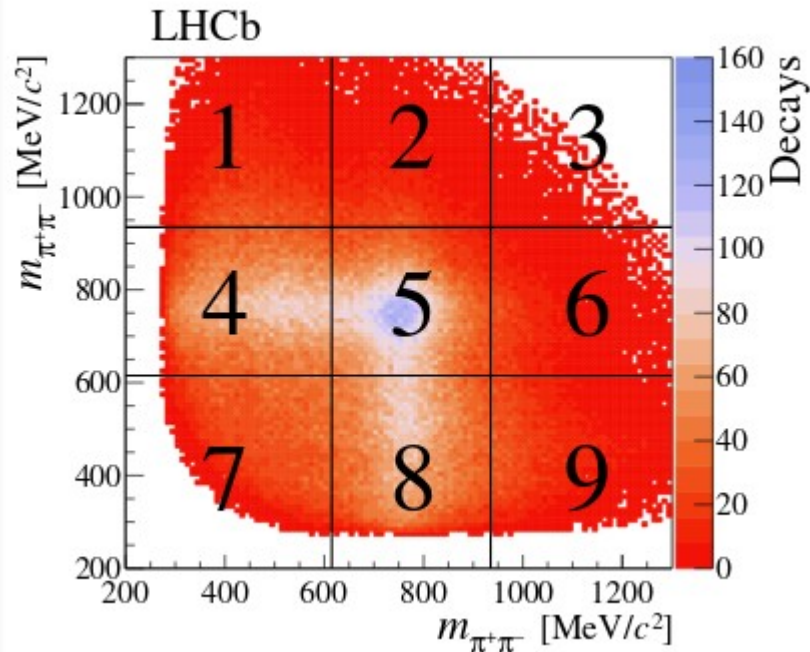
[Angelescu, Faroughy, **OS**. To appear]

but more model dependent (EFT validity?)

<u>Take-home</u>: Different approaches are complementary!

# Good village, good neighbors...

Julien



$R:(5)\times(5)$; $CR:(4, 5, 8)\times(4, 8)$; $BR:(1, 3, 7, 9)\times-$

Phys. Rev. D 88, 093012 (2013)
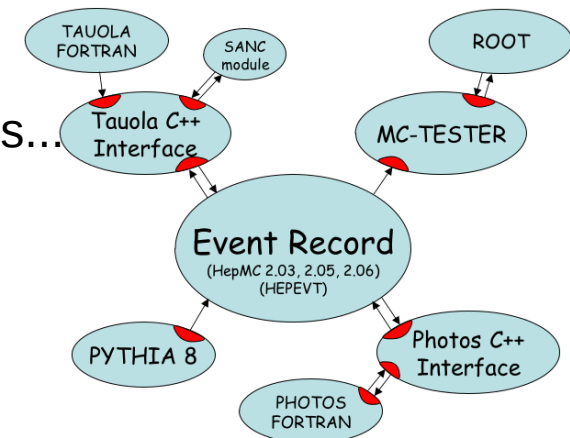
**TAUOLA (w/BaBar data for 3pi) – Prof. Was**

A Love/Struggle story of ~30 years, with some hadronic current wishes...

Many coding languages... and still developing..

"Some physicists want to know what they are doing"

" The user better not know what he's doing, cause otherwise he might destroy physics"

# And more... before

Current bounds set on rare $B$ decays with $\tau$ already provide strong constraints on some models proposed to explain the flavour anomalies, e.g.

C. Cornella, J. Fuentes-Martin and G. Isidori, JHEP 07(2019)168 v1



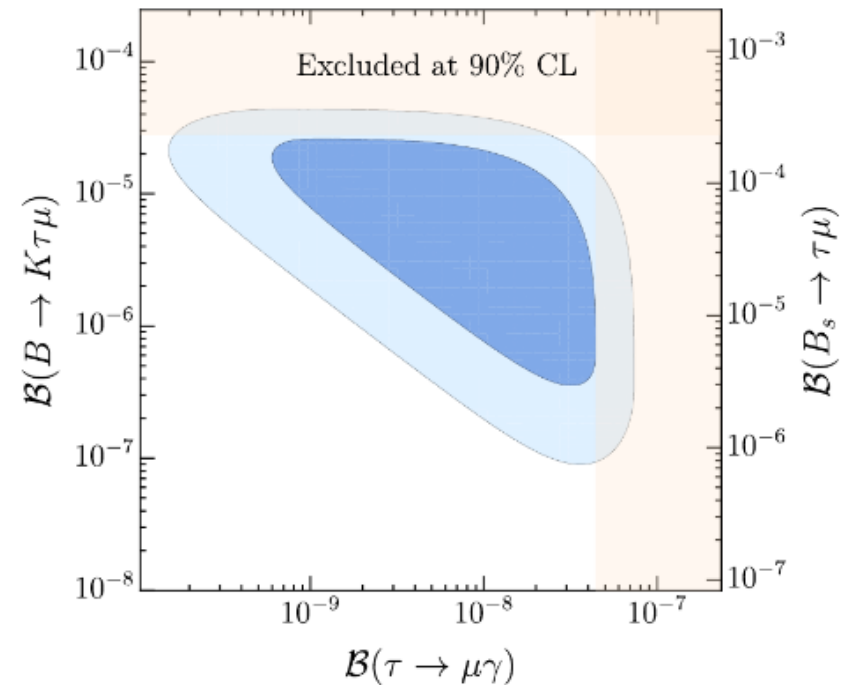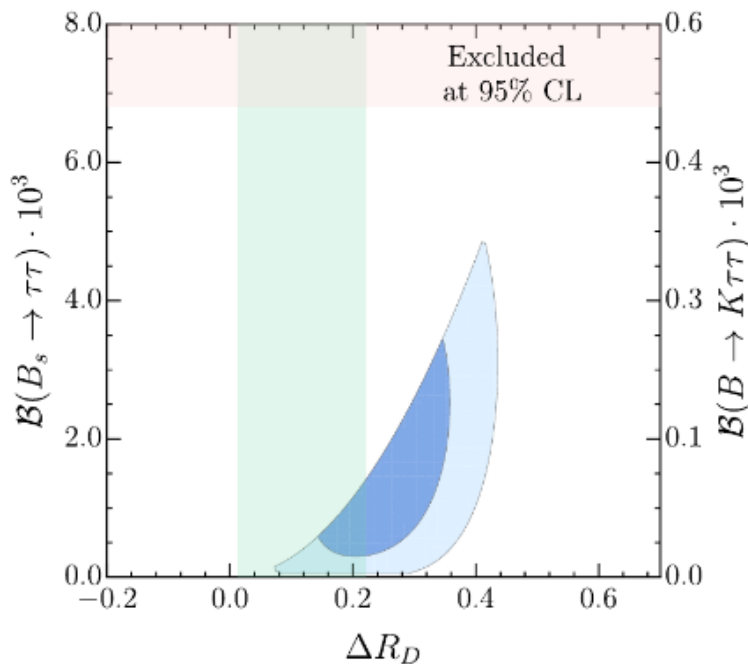Before $B_s^0 \to \tau^\pm \mu^\mp$ measurement

# And more... after !

Current bounds set on rare $B$ decays with $\tau$ already provide strong constraints on some models proposed to explain the flavour anomalies, e.g.

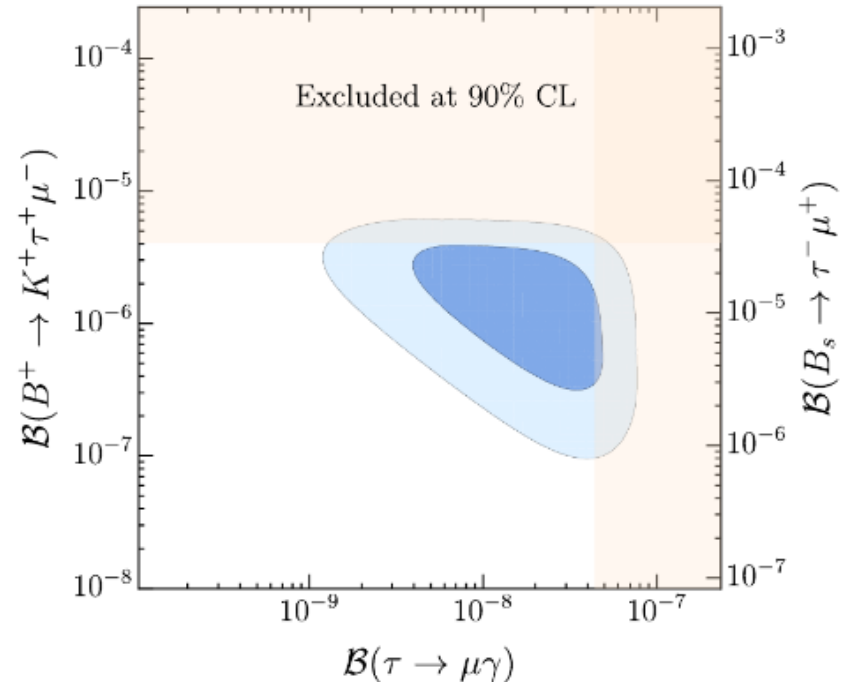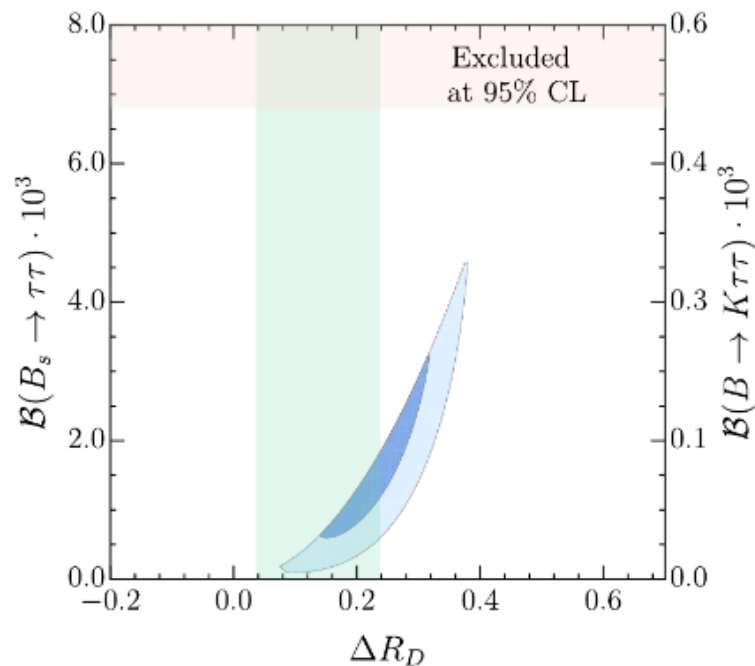C. Cornella, J. Fuentes-Martin and G. Isidori, JHEP 07(2019)168 v2



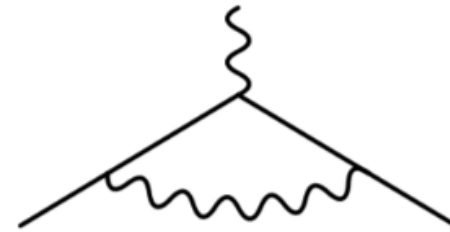After $B_s^0 \to \tau^\pm \mu^\mp$ measurement

Julien, LHCb result

# $(g-2)_\ell$ as a probe of new physics

- Long-standing discrepancy $[\approx 3.6\,\sigma]$ in $(g-2)_\mu$:

$$a_\mu^{\text{exp}} = 116592089(63) \times 10^{-11}$$
$$a_\mu^{\text{SM}} = 116591820(36) \times 10^{-11}$$



Olcyr

[Brookhaven, '06]
[Keshavarzi et al., '18], [Davier et al. '19]

$\Rightarrow$ Signal of new bosons coupled to muons?

Perhaps a leptoquark? [Cheung, '01], [Coluccio, '16], [Dorsner, Fajfer, **OS**. '19]

$\Rightarrow$ New results by *Muon g − 2* at Fermilab coming soon!

- New determination of $\alpha$ [Cs. '18] shows a $[2.4\sigma]$ discrepancy in $(g-2)_e$:

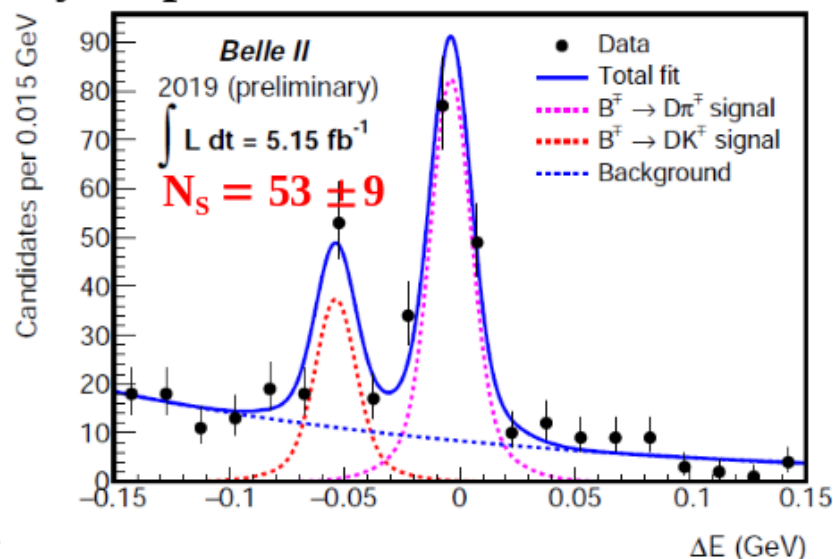$$a_e^{\text{exp}} = 11596521807.3(2.8) \times 10^{-13}$$
$$a_e^{\text{SM}} = 11596521816.1(2.3)_{\delta_\alpha}(0.2)_{\text{th}} \times 10^{-13}$$

(with the opposite sign!)

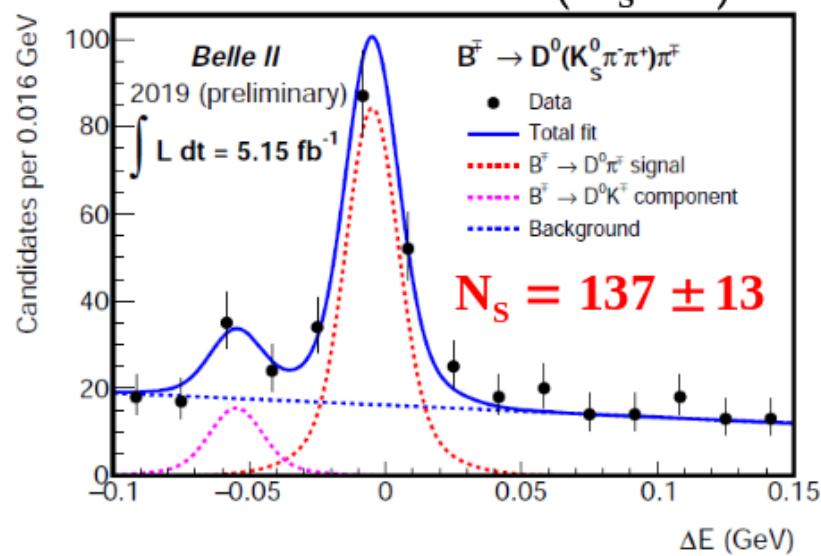$\Rightarrow$ Work in progress to further reduce the error in $(g-2)_e^{\text{exp}}$ and $\delta\alpha$.

# LFV tau decays

Olcyr, Karim



Simultaneous explanations of the (g − 2) e and (g − 2) μ →
Solutions which can lead to large B(τ → eγ) → testable at Belle II

# Present and future: Belle II

**step by step... observation of B → DK**



**...observation of B → D(K$_S$ππ)π**



Karim

$\left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right|$

**projection for 50 ab$^{-1}$**
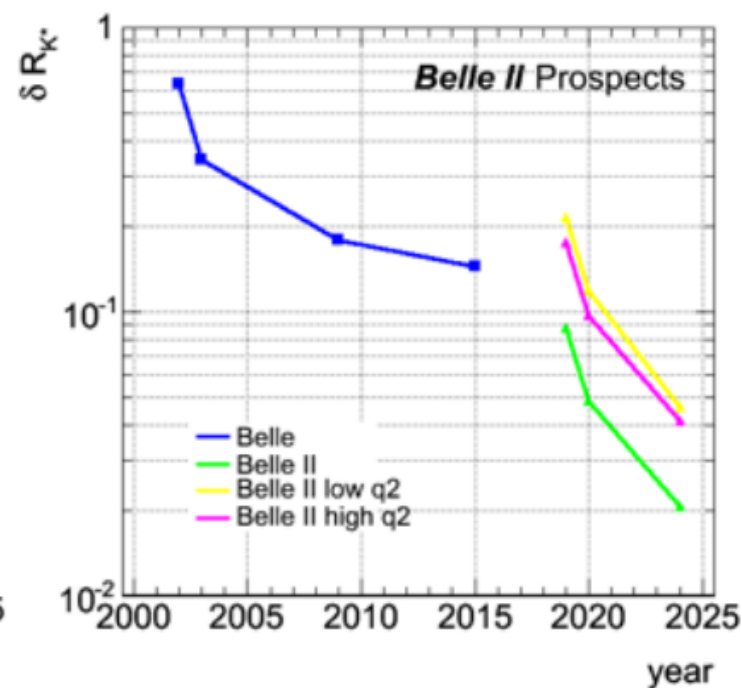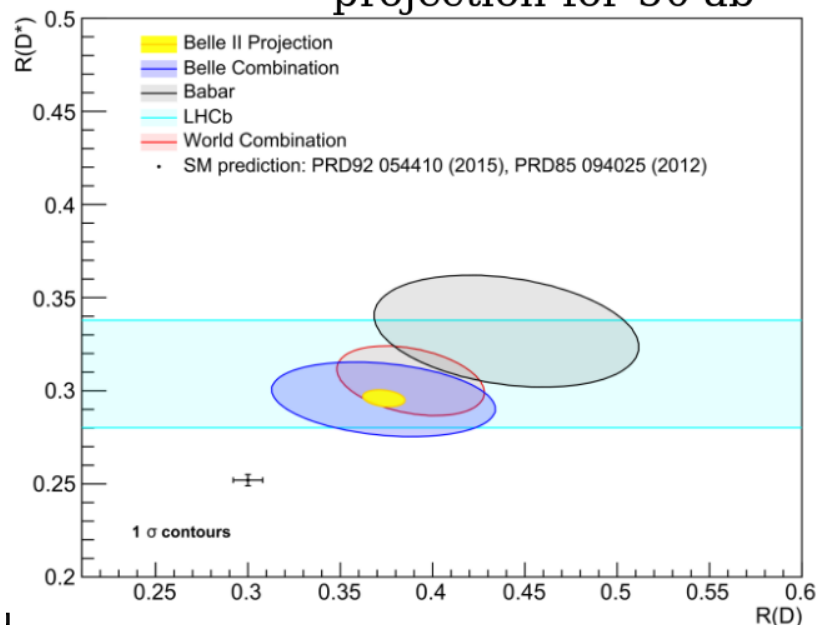
# More prospects Belle II & FCC

| Observables | Belle 0.71 ab$^{-1}$ (0.12 ab$^{-1}$) | Belle II 5 ab$^{-1}$ | Belle II 50 ab$^{-1}$ |
|---|---|---|---|
| Br($B^+ \to K^+ \tau^+ \tau^-$) $\cdot 10^5$ | < 32 | < 6.5 | < 2.0 |

| Observables | Belle 0.71 ab$^{-1}$ (0.12 ab$^{-1}$) | Belle II 5 ab$^{-1}$ | Belle II 50 ab$^{-1}$ |
|---|---|---|---|
| Br($B^+ \to K^+ \tau^{\pm} e^{\mp}$) $\cdot 10^6$ | – | – | < 2.1 |
| Br($B^+ \to K^+ \tau^{\pm} \mu^{\mp}$) $\cdot 10^6$ | – | – | < 3.3 |
| Br($B^0 \to \tau^{\pm} e^{\mp}$) $\cdot 10^5$ | – | – | < 1.6 |
| Br($B^0 \to \tau^{\pm} \mu^{\mp}$) $\cdot 10^5$ | – | – | < 1.3 |

Karim

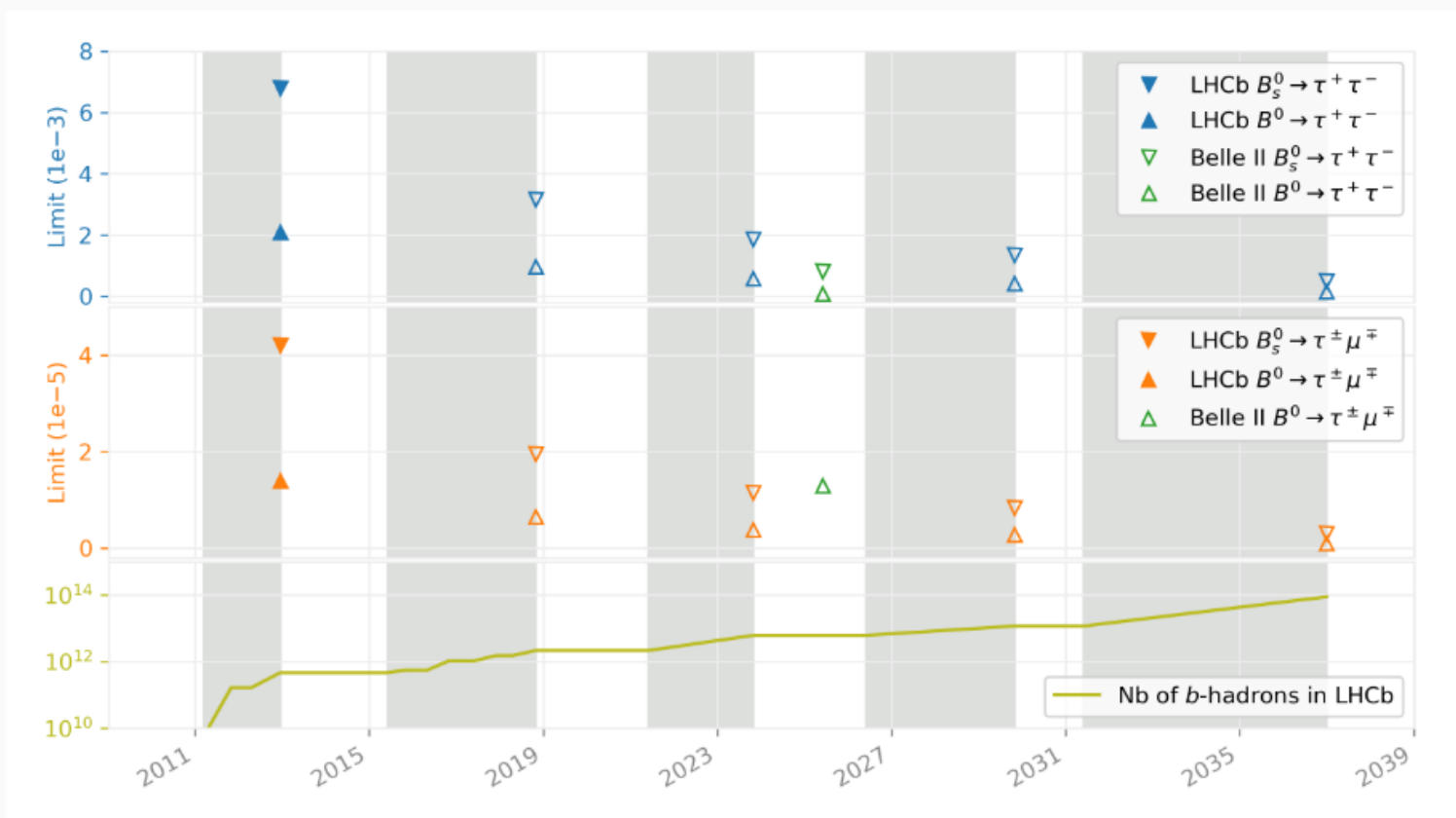| Decay mode | $B^0 \to K^*(892)e^+e^-$ | $B^0 \to K^*(892)\tau^+\tau^-$ | $B_s(B^0) \to \mu^+\mu^-$ |
|---|---|---|---|
| Belle II | ∼ 2 000 | ∼ 10 | n/a (5) |
| LHCb Run I | 150 | - | ∼ 15 (–) |
| LHCb Upgrade | ∼ 5000 | - | ∼ 500 (50) |
| FCC-ee | ∼ 200000 | ∼ 1000 | ∼1000 (100) |

Stephane

FCC Design Study

# Prospects – LHCb/Belle II

Julien

## Prospects

Scaling the current limits with the expected increase in statistics



Belle II with $5\,\mathrm{ab}^{-1}$ @ $\Upsilon(5S)$ for the $B_s^0$ mode and $50\,\mathrm{ab}^{-1}$ @ $\Upsilon(4S)$ for the $B^0$ modes
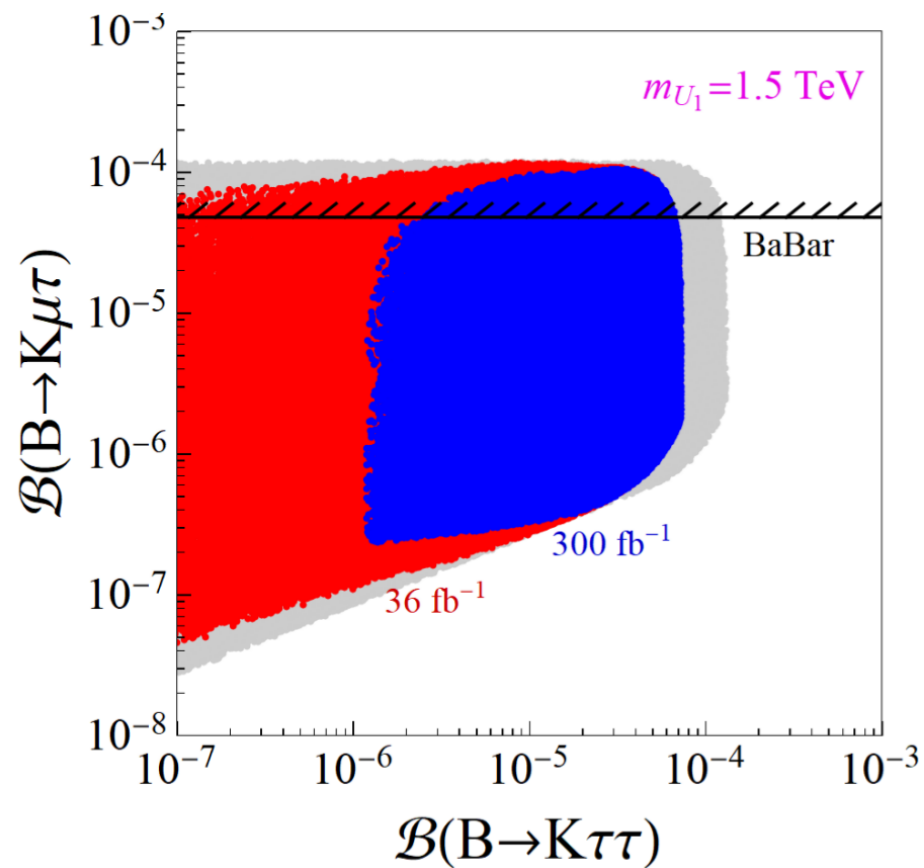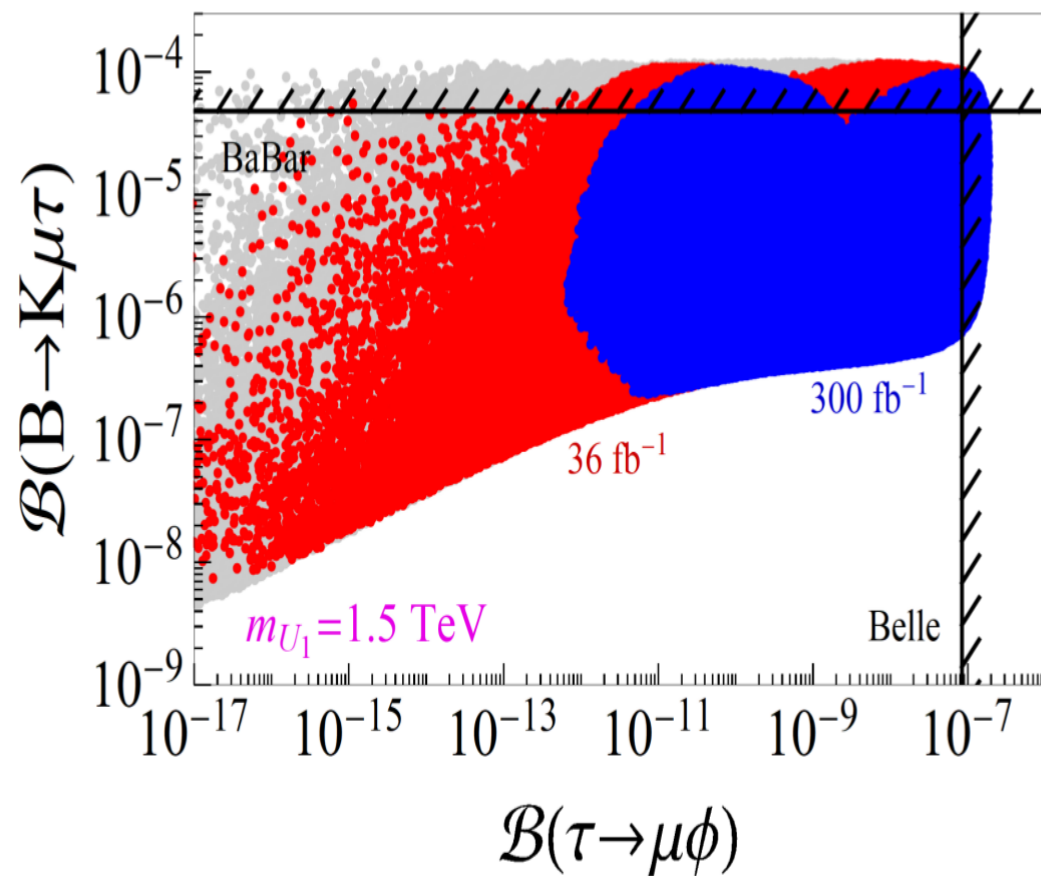
[Belle II Physics book, arXiv:1808.10567]
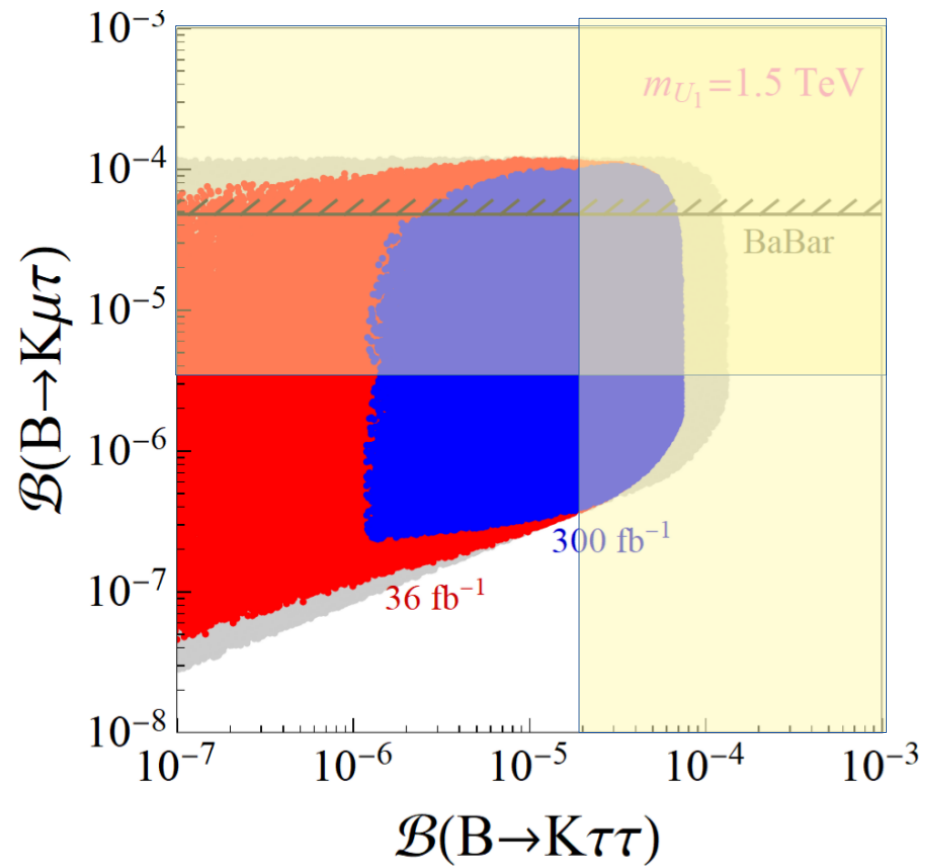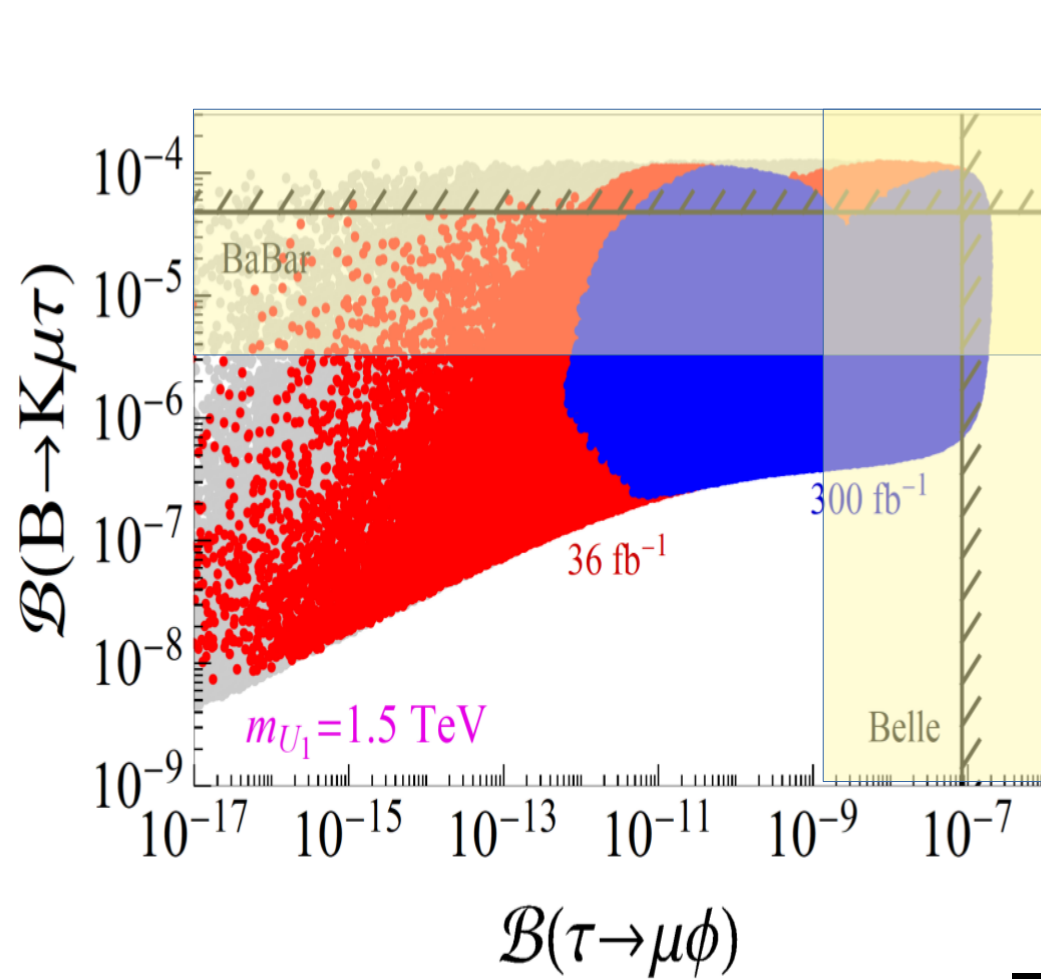
# But for the moment the state of the art is...

| Modes | SM prediction | Exp. (limit @ 90% CL) | Julien LHCb |
|---|---|---|---|
| $B^0 \to \tau^+\tau^-$ | $(2.22 \pm 0.19)\,10^{-8}$ [1] | $< 1.6\,10^{-3}$ [3] | published |
| $B_s^0 \to \tau^+\tau^-$ | $(7.73 \pm 0.49)\,10^{-7}$ [1] | $< 5.2\,10^{-3}$ [3] | |
| $B^+ \to K^+\tau^+\tau^-$ | $(1.20 \pm 0.12)\,10^{-7}$ [2] | $< 2.3\,10^{-3}$ [4] | - |
| $B^0 \to K^{*0}\tau^+\tau^-$ | $(0.98 \pm 0.10)\,10^{-7}$ [2] | - | in progress |
| $B^0 \to \tau^\pm e^\mp / \tau^\pm \mu^\mp$ | × | $< 2.8\,10^{-5}$ [5] / $< 1.2\,10^{-5}$ [6] | published |
| $B_s^0 \to \tau^\pm e^\mp / \tau^\pm \mu^\mp$ | × | - / $< 3.4\,10^{-5}$ [6] | |
| $B^+ \to \pi^+\tau^\pm e^\mp / \pi^+\tau^\pm \mu^\mp$ | × | $< 7.5\,10^{-5}$ [7] / $< 7.2\,10^{-5}$ [7] | - |
| $B^+ \to K^+\tau^\pm e^\mp / K^+\tau^\pm \mu^\mp$ | × | $< 3.0\,10^{-5}$ [7] / $< 4.8\,10^{-5}$ [7] | in progress |
| $B^0 \to K^{*0}\tau^\pm e^\mp / K^{*0}\tau^\pm \mu^\mp$ | × | - | in progress |

[1] C. Bobeth et al., PRL 112,101801(2014), [2] B. Capdevila et al., PRL 120,181802(2018) (average over the neutral and charged modes), [3] LHCb, PRL 118,251802(2017), [4] BaBar, PRL 118,031802(2017), [5] BaBar, Phys.Rev.D77,091104(2008), [6] LHCb, arXiv:1905.06614, [7] BaBar, Phys.Rev.D86,012004(2012)
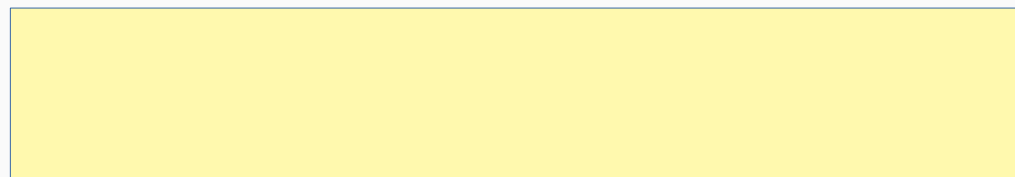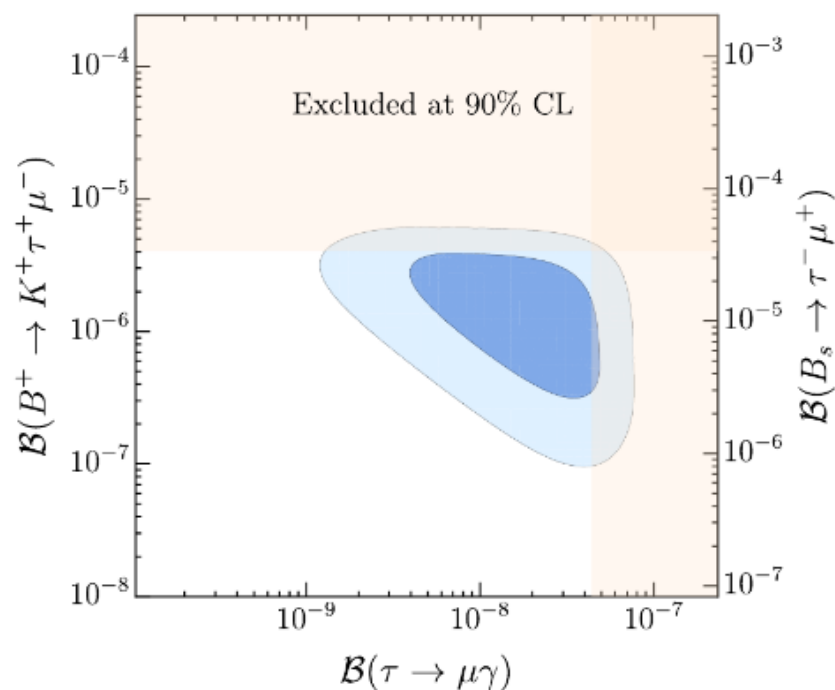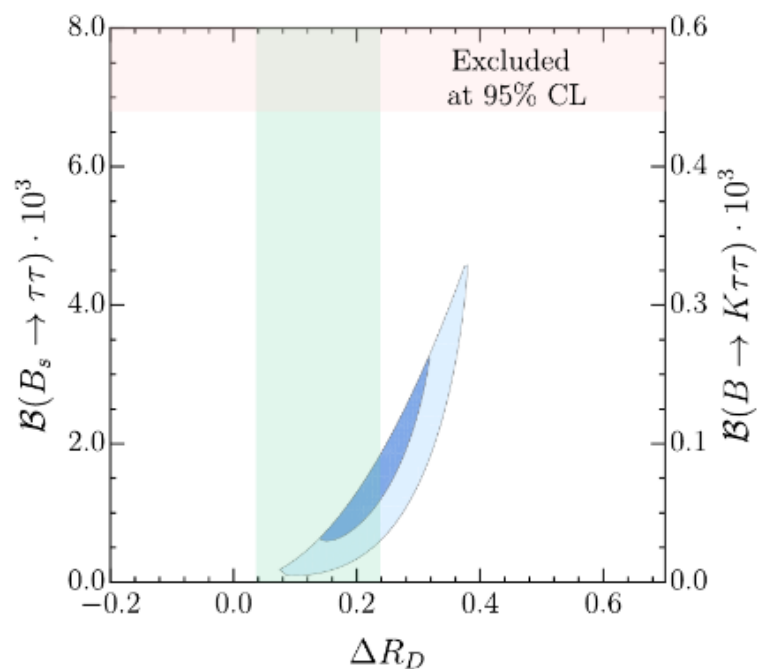
# Before

# After



Belle II

$\mathcal{B}(\mathrm{B}{\to}\mathrm{K}\mu\tau)$ vs $\mathcal{B}(\tau{\to}\mu\phi)$

- BaBar
- $m_{U_1}=1.5$ TeV
- 36 fb$^{-1}$
- 300 fb$^{-1}$
- Belle

$\mathcal{B}(\mathrm{B}{\to}\mathrm{K}\mu\tau)$ vs $\mathcal{B}(\mathrm{B}{\to}\mathrm{K}\tau\tau)$

- $m_{U_1}=1.5$ TeV
- BaBar
- 36 fb$^{-1}$
- 300 fb$^{-1}$

# Before

Current bounds set on rare *B* decays with $\tau$ already provide strong constraints on some models proposed to explain the flavour anomalies, e.g.

C. Cornella, J. Fuentes-Martin and G. Isidori, JHEP 07(2019)168 v2

# After

Current bounds set on rare $B$ decays with $\tau$ already provide strong constraints on some models proposed to explain the flavour anomalies, e.g.
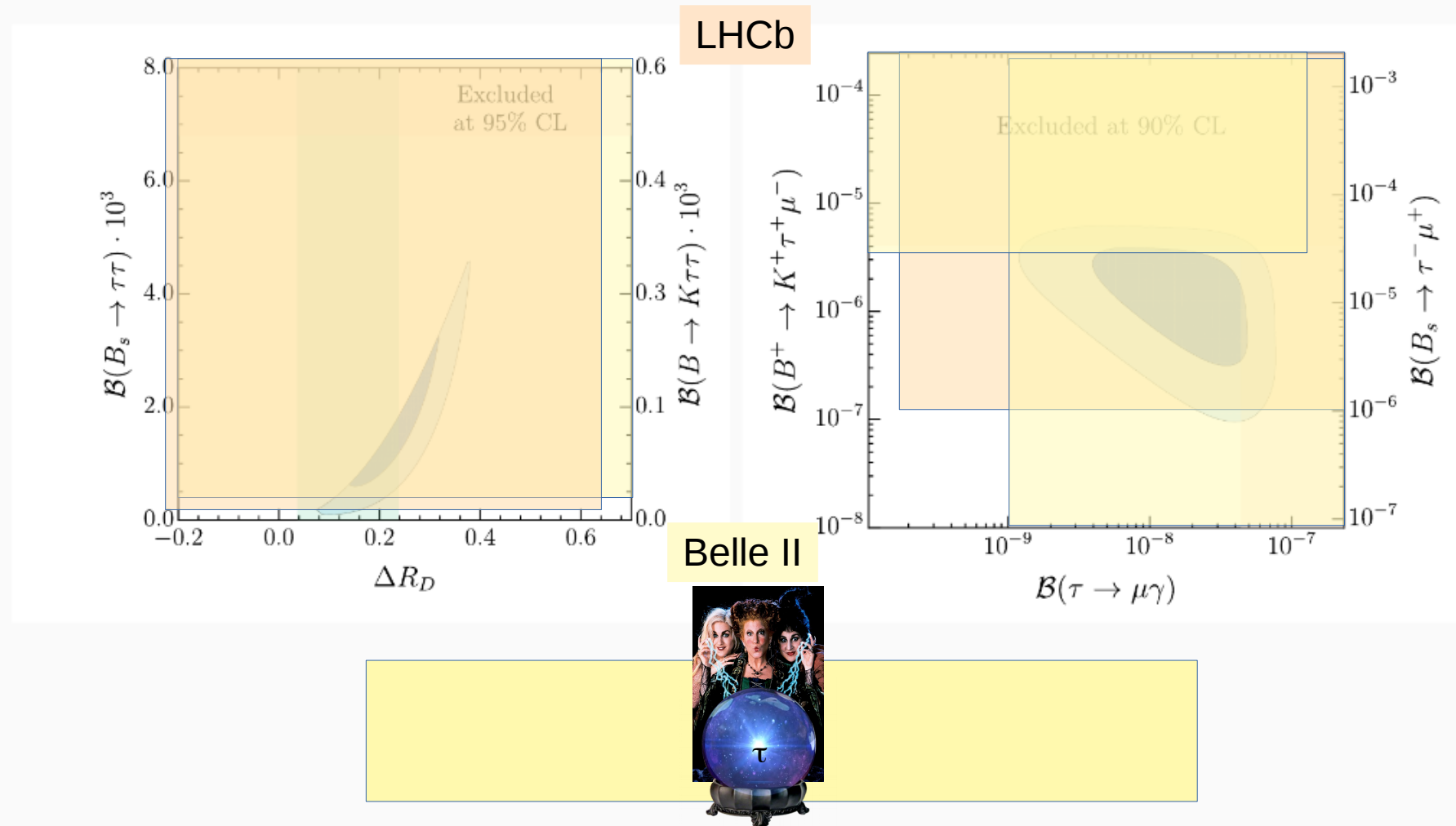
C. Cornella, J. Fuentes-Martin and G. Isidori, JHEP 07(2019)168 v2

LHCb



Belle II

# Time for discussion...