Implications of new measurements of $b \to s\mu\mu$

J. Martin Camalich

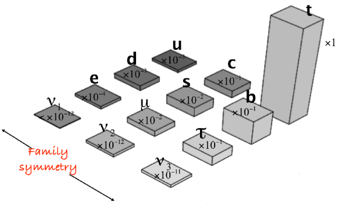
Based largely on L.-S. Geng, B. Grinstein, S. Jäger, S.-Y. Li, JMC, R.-X. Shi
2103.12738 [hep-ph]

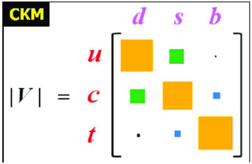
HIDDeN Webinar

April 13th 2021

Why studying (quark) Flavor Physics in the 2020's? 1 - Big Questions

- CKM and mass matrices: **Parametrizations** of flavor phenomena in the SM



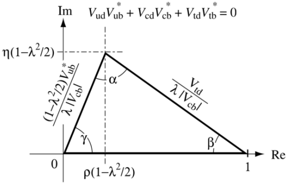


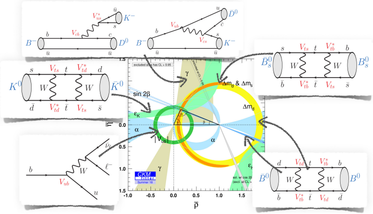
The SM Flavor Puzzle

- Some quark masses seem "tuned"
  Anthropic arguments!
- Origin of *CP*-violation, baryogenesis, strong *CP*
- **Why does Nature need three generations at all?**

- **However,** the solution might not be accessible at the energies at reach. . .

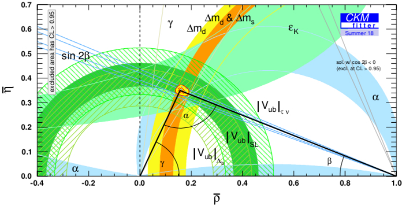
2 - Strong physics programme for the decade



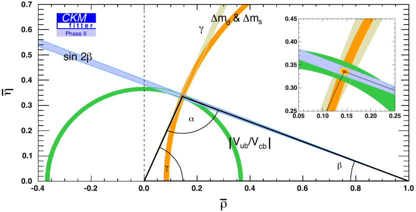


Jure Zupan, arXiv: 1903.05062

- **Current**



- **Projection HL-LHC only**

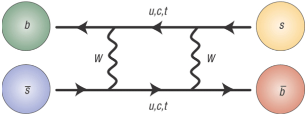


"Opportunities in Flavour Physics at the HL-LHC and HE-LHC", A. Cerri *et al.*, CERN Yellow Rep.Monogr. 7 (2019) 867-1158

Belle II is just ramping up luminosity!

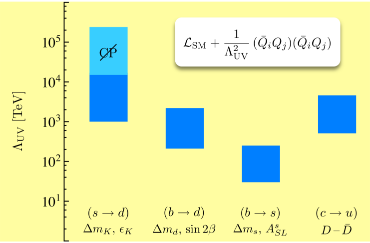
Very sensitive probes of "generic" new physics

- **Theorem:** FCNC are **"Loop-Suppressed"** in the SM!
  - **Prototypical example:** FCNCs



$$\mathcal{M}_{\rm SM} \sim \overbrace{G_F}^{\text{Weak}} \underbrace{\overbrace{\frac{y_t^2}{16\pi^2}}^{\text{Loop}} \overbrace{(V_{ts}^* V_{tb})^2}^{\text{Flavor}}}_{\text{GIM}}$$

  - Flavour observables probe (indirectly) very high energy scales!



Generic bounds without a flavor symmetry

M. Neubert at EPS 2011

Flavor physics was instrumental in **discovering** and **shaping** the SM

- **Nuclear β-decays:** Discovery **weak interactions** and **neutrino**
- **Rare Kaon-decays:** Discovery of the **charm quark**
- **Kaon decays:** Discovery of *CP* **violation** $\Longrightarrow$ Discovery of **3 generations**

- **Expect the unexpected**

PROPOSAL FOR K^o_2 DECAY AND INTERACTION EXPERIMENT

J. W. Cronin, V. L. Fitch, R. Turlay

(April 10, 1963)

I. INTRODUCTION

The present proposal was largely stimulated by the recent anomalous results of Adair et al., on the coherent regeneration of K^o_1 mesons. It is the purpose of this experiment to check these results with a precision far transcending that attained in the previous experiment. Other results to be obtained will be a new and much better limit for the partial rate of $K^o_2 \rightarrow \pi^+ + \pi^-$, a new limit for the presence (or absence) of neutral currents as observed through $K_2 \rightarrow \mu^+ + \mu^-$.

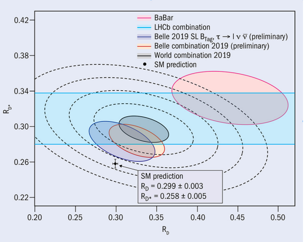
Thanks to Zoltan Ligeti for sharing this

3 - Flavor anomalies!

- **Lepton-universality violation in *B* decays?**

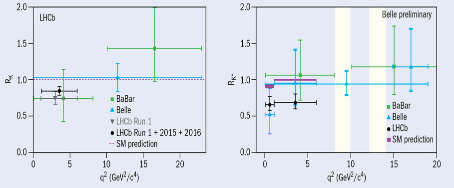
"The flavour of new physics", JMC & J. Zupan, CERN courier, May/June 2019

- **"$R_{D^{(*)}}$ anomaly"** in $B \to D^{(*)}\ell\nu$!



- ***Excesses*** observed at $\sim 3\sigma$
- Other "anomalies" in $b \to (u, c)\ell\nu$
- **Charged Current:** $\Lambda_{\rm NP} \sim 3$ TeV

- **"$R_{K^{(*)}}$ anomaly"** in $B \to K\ell\ell$ (**FCNC**)!



- Other anomalies in $b \to s\mu\mu$
  - ★ Branching fractions
  - ★ Angular analysis $B \to K^*\mu\mu$
- Up to **several σ in global fits**
- **FCNC:** $\Lambda_{\rm NP} \sim 30$ TeV

Our previous analyses of $b \to s\ell\ell$

1. **Anatomy and model-independent parametrization of hadronic uncertainties**

   Beneke *et al.* NPB592(2001)3, Jäger and JMC JHEP1305(2013)043, PRDD93(2016)1,014028

   - Were at the center of "P_5' controversies" (hadronic effects vs. NP)

     Bharucha *et al.*JHEP 1009 (2010) 090, Descotes-Genon *et al.* JHEP 1412 (2014) 125, Lyon *et al.* arXiv:1406.0566, Ciuchini *et al.* arXiv:1512.07157 + many, many more papers...

2. **First theoretical analysis of the first R_K measurement**

PRL **113,** 241802 (2014) PHYSICAL REVIEW LETTERS week ending 12 DECEMBER 2014

$SU(2) \times U(1)$ Gauge Invariance and the Shape of New Physics in Rare B Decays

R. Alonso,[1,*] B. Grinstein,[1] and J. Martin Camalich[1,2]

[1]*Department of Physics, University of California, San Diego, 9500 Gilman Drive, La Jolla, California 92093-0319, USA*

[2]*PRISMA Cluster of Excellence Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany*

(Received 18 August 2014; published 9 December 2014)

3. **Among first combined theoretical analyses of $R_{K^{(*)}}$**

PHYSICAL REVIEW D **96,** 093006 (2017)

Towards the discovery of new physics with lepton-universality ratios of $b \to s\ell\ell$ decays

Li-Sheng Geng,[1] Benjamín Grinstein,[2] Sebastian Jäger,[3] Jorge Martin Camalich,[4] Xiu-Lei Ren,[5,6] and Rui-Xiang Shi[1]

Emphasize lepton-universality ratios and $B_s \to \mu\mu$ to discover NP

- **Announcement of new LHCb results on R_K and $B_s \to \mu\mu$!**

LHC Seminar

New results on theoretically clean observables in rare B-meson decays from LHCb

por Konstantinos Petridis (University of Bristol (GB)) , Marco Santimaria (INFN e Laboratori Nazionali di Frascati (IT))

martes 23 mar. 2021 11:00 → 12:00 Europe/Zurich

Descripción Over the past decade, measurements involving the flavour changing neutral current transition $b \to s\ell+\ell-$ have shown tantalising tensions with Standard Model (SM) predictions. However, our current understanding of the hadronic uncertainties in these predictions potentially hinders our ability to interpret these results as physics beyond the SM. In order to resolve this impasse, measurements of observables that are theoretically pristine in processes that are accidentally suppressed in the SM are of paramount importance. In this two-part seminar, we will present new results on two key processes using the complete dataset collected by the LHCb experiment so far.

- **Quick (last-second) reaction to analyse the new results**

Implications of new evidence for lepton-universality violation in $b \to s\ell^+\ell^-$ decays

Li-Sheng Geng, Benjamín Grinstein, Sebastian Jäger, Shuang-Yi Li, Jorge Martin Camalich, Rui-Xiang Shi

Motivated by renewed evidence for New Physics in $b \to s\ell\ell$ transitions in the form of LHCb's new measurements of theoretically clean lepton-universality ratios and the purely leptonic $B_s \to \mu^+\mu^-$ decay, we quantify the combined level of discrepancy with the Standard Model and fit values of short-distance Wilson coefficients. A combination of the clean observables R_K, R_{K^*}, and $B_s \to \mu\mu$ alone results in a discrepancy with the Standard Model at 4.0σ, up from 3.5σ in 2017. One-parameter scenarios with purely left-handed or with purely axial coupling to muons fit the data well and exclude the Standard Model at $\sim 5\sigma$ level. In a two-parameter fit to %C_9 and C_{10}, new-physics contributions with both vector and axial-vector couplings to muons the allowed region is much more defined than in 2017, principally due to the much more precise result on $B_s \to \mu^+\mu^-$, which probes the axial coupling to muons. Including angular observables data narrows the allowed region further. A by-product of our analysis is an updated average of $\mathrm{BR}(B_s \to \mu^+\mu^-) = (2.8 \pm 0.3) \times 10^{-9}$.

Comments: Improvements to presentation, some clarifications added, input data treatment modified to match 2017 treatment, one reference added, conclusions unchanged
Subjects: **High Energy Physics - Phenomenology (hep-ph)**; High Energy Physics - Experiment (hep-ex)
Cite as: arXiv:2103.12738 **[hep-ph]**
(or arXiv:2103.12738v2 **[hep-ph]** for this version)

Submission history

From: Li-Sheng Geng [view email]
[v1] Tue, 23 Mar 2021 17:59:59 UTC (233 KB)

- **Announcement of new LHCb results on R_K and $B_s \to \mu\mu$!**

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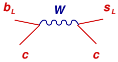
- **Collaboration between:**
  - Beihang University: Li-Sheng Geng, **Shuang-Yi Li** and **Rui-xiang Shi**
  - UC San Diego: Benjamín Grinstein
  - U. Sussex: Sebastian Jäger
  - Instituto de Astrofísica de Canarias: JMC
- **Other related work appeared around the same time:**

Hiller *et al.* 2103.12724 [hep-ph], Angelescu *et al.* 2103.12504 [hep-ph], Altmannshofer *et al.* 2103.13370 [hep-ph], Cornella *et al.* 2103.16558 [hep-ph], Greljo *et al.* 2103.13991 [hep-ph], . . .

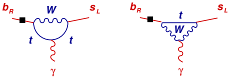
Effective field theory approach to $b \to s\ell\ell$ decays

- **CC** (Fermi theory):

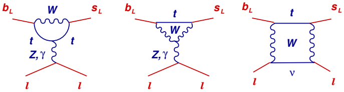


$$\Rightarrow \quad G_F\, V_{cb}\, V^*_{cs}\, C_2\, \bar{c}_L \gamma^\mu b_L\, \bar{s}_L \gamma_\mu c_L$$

- **FCNC**:

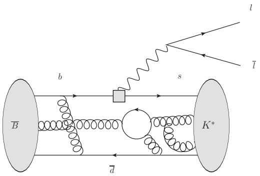


$$\Rightarrow \quad \frac{e}{4\pi^2}\, G_F\, V_{tb}\, V^*_{ts}\, m_b\, C_7\, \bar{s}_L \sigma_{\mu\nu} b_R\, F^{\mu\nu}$$



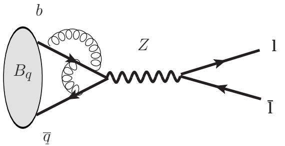
$$\Rightarrow \quad G_F\, V_{tb}\, V^*_{ts}\, \frac{\alpha}{4\pi}\, C_{9(10)}\, \bar{s}_L \gamma^\mu b_L\, \bar{\ell}\gamma_\mu(\gamma_5)\ell$$

- ▶ **New-Physics** also in C_i or e.g. $\mathcal{O}'_i$ obtained $P_L \to P_R$ in $\bar{s}_L b$



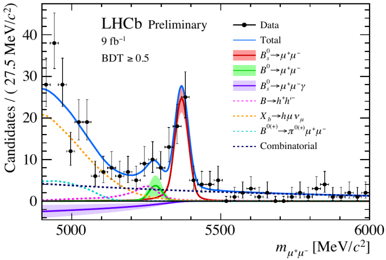
- ▶ Light fields active at long distances
  Nonperturbative QCD!
  - ★ Factorization of scales m_b *vs.* $\Lambda_{\rm QCD}$
    HQEFT, QCDF, SCET,. . .

A beautiful example: $B_q^0 \to \ell\ell$



$$\mathcal{B}_{s\ell} \propto G_F^2 \alpha^2 |V_{tb} V_{ts}^*|^2 m_\ell^2 f_{B_s}^2 |C_{10} - C_{10}'|^2$$

Marco Santimaria @ CERN, March 23rd 2021



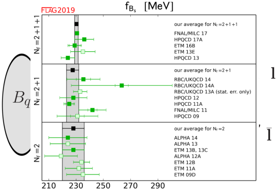
- $\mathscr{B}(B_s^0 \to \mu^+\mu^-) = (3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9}$ (10.8σ)

- Semileptonic decay **constants** f_{B_q} can be calculated in LQCD FLAG averages
- $\sim 2-3\sigma$ **deficit with respect to SM predictions!**

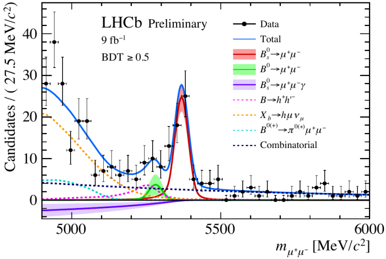
Beneke *et al.* JHEP10(2019)232

$$\overline{\mathcal{B}}_{s\mu}^{\rm SM} = 3.66(14) \times 10^{-9}$$

A beautiful example: $B_q^0 \to \ell\ell$



Marco Santimaria @ CERN, March 23rd 2021



$$\mathcal{B}_{s\ell} \propto G_F^2 \alpha^2 |V_{tb} V_{ts}^*|^2 m_\ell^2 f_{B_s}^2 |C_{10} - C'_{10}|^2$$

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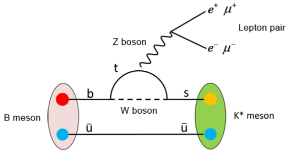
Beneke *et al.* JHEP10(2019)232

$$\overline{\mathcal{B}}^{\rm SM}_{s\mu} = 3.66(14) \times 10^{-9}$$

A rich (and complex) example: $B \to K^*(\to K\pi)\ell\ell$



$$\frac{d^{(4)}\Gamma}{dq^2\, d(\cos\theta_l) d(\cos\theta_k) d\phi} = \frac{9}{32\pi} \big(I_1^s \sin^2\theta_k + I_1^c \cos^2\theta_k$$
$$+ \quad (I_2^s \sin^2\theta_k + I_2^c \cos^2\theta_k)\cos 2\theta_l + I_3 \sin^2\theta_k \sin^2\theta_l \cos 2\phi$$
$$+ \quad I_4 \sin 2\theta_k \sin 2\theta_l \cos\phi + \mathbf{I_5} \sin 2\theta_k \sin\theta_l \cos\phi + I_6 \sin^2\theta_k \cos\theta_l$$
$$+ \quad I_7 \sin 2\theta_k \sin\theta_l \sin\phi + I_8 \sin 2\theta_k \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_k \sin^2\theta_l \sin 2\phi\big)$$

- **Anomalies in the angular observables ...**

$$P_5' = \frac{I_5}{2\sqrt{-I_{2s} I_{2c}}}$$

- **Cancel leading theory uncertainties**

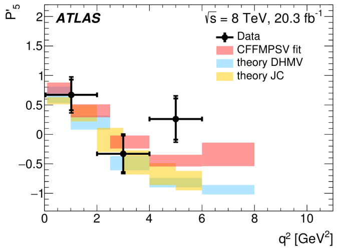
New physics?

$$\delta C_9^{\mu} \simeq -1$$

Descotes-Genon *et al.* PRD88,074002

- **Blurred by hadronic uncertainties**

ATLAS, JHEP 10 (2018) 047



Most precise measurement: LHCb, PRL125(2020)011802

Anatomy of the amplitude in a nutshell

Jäger and JMC, PRD93 (2016) no.1, 014028

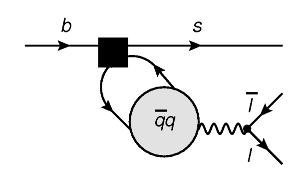
- Helicity amplitudes $\lambda = \pm 1, 0$

$$H_V(\lambda) = -iN\Big\{ \overbrace{\Big[C_9 \tilde{V}_{L\lambda} + \frac{m_B^2}{q^2} h_\lambda \Big]}^{C_9^{\rm eff}} - \frac{\hat{m}_b m_B}{q^2} C_7 \tilde{T}_{L\lambda} \Big\},$$

$$H_A(\lambda) = -iN C_{10} \tilde{V}_{L\lambda}$$

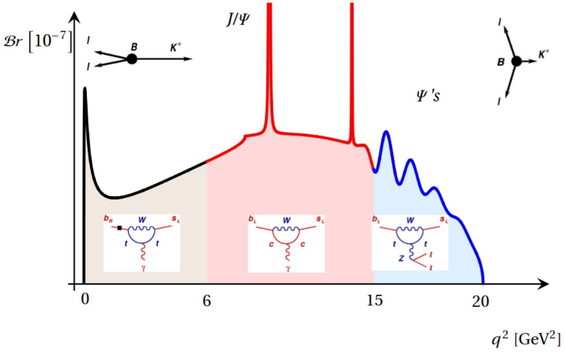
- Hadronic form factors: **7** independent q^2-dependent nonperturbative functions

“Charm” contribution



$$h_\lambda \propto \int d^4y e^{iq\cdot y} \langle \bar{K}^* | T\{ j^{\rm em,had,\mu}(y), \mathcal{O}_{1,2}(0)\} | \bar{B} \rangle$$

- Charm and $\mathcal{O}_9$ are tied up by renormalization
  Only $C_9^{\rm eff}$ is observable!



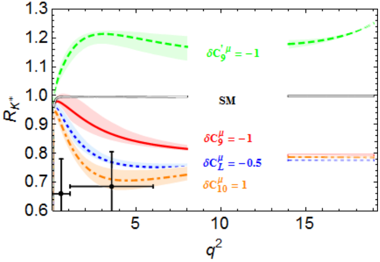
- **Large-recoil region** (low q^2)
  - **No LQCD** (Sum Rules, models ...) and **QCDf** and **SCET** (power-corrections)
  - Dominant effect of the photon pole
- **Charmonium region**
  - Dominated by long-distance (hadronic) effects
  - Starting at the perturbative $c\bar{c}$ threshold $q^2 \simeq 6 - 7$ GeV^2
- **Low-recoil region** (high q^2)
  - **LQCD**+**HQEFT** + **OPE** (duality violation)
  - Dominated by semileptonic operators

The lepton-universality ratios

Leptons do not feel the strong force!

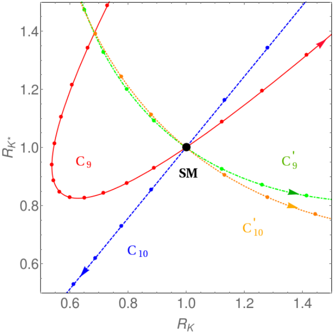
$$R_{K^{(*)}} = \frac{\mathcal{B}(\bar{B}\to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(\bar{B}\to K^{(*)}e^+e^-)} \overset{\text{SM}}{\simeq} 1$$

- **Very clean null tests of the SM**



  - **Th. uncertainties negligible!**

- **Sensitive to muonic LH currents!**

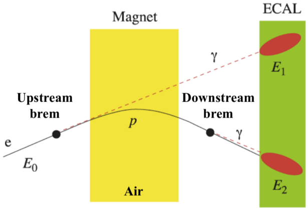


Geng, Grinstein, Jäger, JMC, Ren, Shi, PRD96(2017)093006

The R_K measurement (my interpretation)

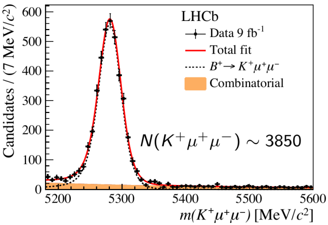
LHCb, PRL122(2019)191801, arXiv: 2103.11769 [hep-ex], K. Petridis @ CERN March 23rd 2021

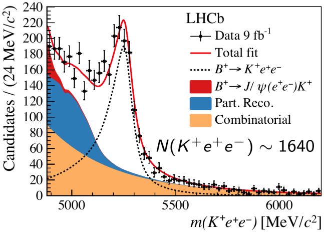
- **Different behavior of μ and e in detector**



  - **Electrons:** Energy losses through bremsstrahlung
  - Reconstruct energy by identifying clusters in ECAL

- **Degraded electron-energy resolution due to reconstruction**





- **LHCb strategy:** Divide by $1 \simeq r_{J\psi} = \mathcal{B}(B^+ \to K^+ J/\psi(\mu\mu))/\mathcal{B}(B^+ \to K^+ J/\psi(ee))$

$$R_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+ J/\psi(\mu^+\mu^-))} \Bigg/ \frac{\mathcal{B}(B^+ \to K^+ e^+e^-)}{\mathcal{B}(B^+ \to K^+ J/\psi(e^+e^-))} = \frac{N^{\rm rare}_{\mu^+\mu^-}\, \varepsilon^{J/\psi}_{\mu^+\mu^-}}{N^{J/\psi}_{\mu^+\mu^-}\, \varepsilon^{\rm rare}_{\mu^+\mu^-}} \times \frac{N^{J/\psi}_{e^+e^-}\, \varepsilon^{\rm rare}_{e^+e^-}}{N^{\rm rare}_{e^+e^-}\, \varepsilon^{J/\psi}_{e^+e^-}}$$

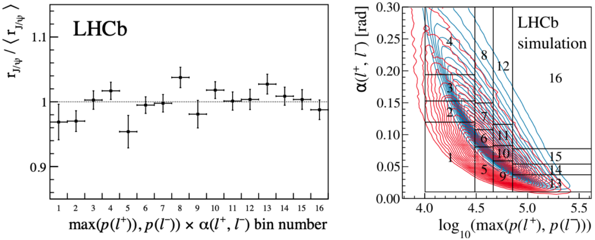
  - Supress much of the systematic uncertainties

- **First cross-check:** Measure $R_{\psi(2S)}$

$$R_{\psi(2S)} = \frac{\mathcal{B}(B^+ \to K^+ \psi(2S)(\mu^+\mu^-))}{\mathcal{B}(B^+ \to K^+ J/\psi(\mu^+\mu^-))} \Bigg/ \frac{\mathcal{B}(B^+ \to K^+ \psi(2S)(e^+e^-))}{\mathcal{B}(B^+ \to K^+ J/\psi(e^+e^-))}$$

  - They obtain $R_{\psi(2S)} = 0.997(11)$ (world-leading test of LFU in $\psi(2S) \to \ell\ell$)

- **Second cross-check:** Check efficiencies by $r_{J/\psi} \simeq 1$ in different kinematics



- **LHCb strategy:** Divide by $1 \simeq r_{J\psi} = \mathcal{B}(B^+ \to K^+ J/\psi(\mu\mu))/\mathcal{B}(B^+ \to K^+ J/\psi(ee))$

$$R_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+ J/\psi(\mu^+\mu^-))} \Bigg/ \frac{\mathcal{B}(B^+ \to K^+ e^+e^-)}{\mathcal{B}(B^+ \to K^+ J/\psi(e^+e^-))} = \frac{N^{\mathrm{rare}}_{\mu^+\mu^-}\ \varepsilon^{J/\psi}_{\mu^+\mu^-}}{N^{J/\psi}_{\mu^+\mu^-}\ \varepsilon^{\mathrm{rare}}_{\mu^+\mu^-}} \times \frac{N^{J/\psi}_{e^+e^-}\ \varepsilon^{\mathrm{rare}}_{e^+e^-}}{N^{\mathrm{rare}}_{e^+e^-}\ \varepsilon^{J/\psi}_{e^+e^-}}$$

  - Supress much of the systematic uncertainties

- **Final LHCb result of R_K with full run 1 and run 2 data sets**
  - Twice as much data as 2019 analysis!

3 fb^{-1} 7,8 TeV	5 fb^{-1} (+2 fb^{-1} 13 TeV)	9 fb^{-1} (+4 fb^{-1} 13 TeV)
PRL113(**2014**)151601	PRL122(**2019**)191801	arXiv: **2103.11769**
$0.745^{+0.090}_{-0.074} \pm 0.036$	$0.846^{+0.060+0.016}_{-0.054-0.014}$	$0.846^{+0.042+0.013}_{-0.039-0.012}$

  - Expected $\sqrt{2}$ reduction in stat., amusingly identical c.v.

- **Blind analysis**

In order to avoid unconscious bias, the analysis procedure was developed and the cross-checks described below performed before the result for R_K was examined.

arXiv:2103.11769

Fitting strategy and summary new data since 2017

- **The theoretically-clean fit**
  - Only observables with controlled theoretical uncertainties: $B_s \to \mu\mu$ and $R_{K^{(*)}}$

Observable	Value	Source
$BR(B_s \to \mu^+\mu^-)$	$(2.8^{+0.8}_{-0.7}) \times 10^{-9}$	ATLAS
	$(2.9 \pm 0.7 \pm 0.2) \times 10^{-9}$	CMS
	$(3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9}$	LHCb update
	$(2.842 \pm 0.333) \times 10^{-9}$	our average
	$(3.63 \pm 0.13) \times 10^{-9}$	SM prediction
$R_K[1.1, 6]$	0.846 ± 0.044	LHCb
$R_K[1, 6]$	1.03 ± 0.28	Belle
$R_{K^*}[0.045, 1.1]$	0.660 ± 0.113	LHCb
$R_{K^*}[1.1, 6]$	0.685 ± 0.122	LHCb
$R_{K^*}[0.045, 1.1]$	0.52 ± 0.365	Belle
$R_{K^*}[1.1, 6]$	0.96 ± 0.463	Belle

- **Major changes since 2017**
  - ★ New measurements of $B_s \to \mu\mu$

$$R = \mathcal{B}^{\rm expt}_{s\mu} / \mathcal{B}^{\rm SM}_{s\mu}$$

$R = 0.83(16)$ (1σ) $\Rightarrow$ $R = 0.78(9)$ (2.4σ)

  - ★ New measurement of R_K ($9\ fb^{-1}$)

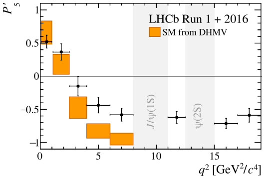
$R = 0.745(90)$ (2.4σ) $\Rightarrow$ $R = 0.846(44)$ (3.1σ)

  - ★ Belle measurements of $R_{K^{(*)}}$

- **The global fit**

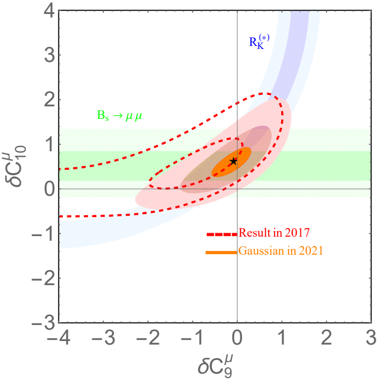
- **Add angular observables $P_i^{(\prime)}$: 94 data**
  - ★ New LHCb data on $B^{0,+} \to K^{*0,+}\mu^+\mu^-$

    LHCb, PRL125(2020)011802 and 2012.13241 [hep-ex]



The theoretically-clean fit

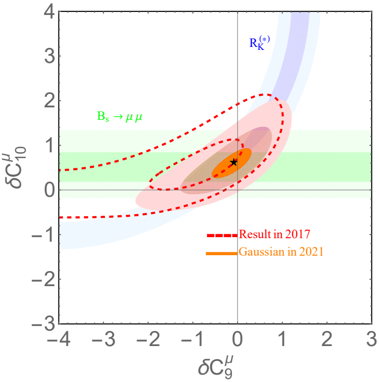
- **Assume NP is μ-specific** (1σ, 3σ and 5σ contours)



Coeff.	best fit	$\chi^2_{\rm min}$	p-value	SM exclusion [σ]	1σ range	3σ range
δC_9^μ	-0.82	14.70 [6 dof]	0.02	4.08	$[-1.06, -0.60]$	$[-1.60, -0.20]$
δC_{10}^μ	0.65	6.52 [6 dof]	0.37	4.98	$[0.52, 0.80]$	$[0.25, 1.11]$
δC_L^μ	-0.40	7.36 [6 dof]	0.29	4.89	$[-0.48, -0.31]$	$[-0.66, -0.15]$
$(\delta C_9^\mu, \delta C_{10}^\mu)$	$(-0.11, 0.59)$	6.38 [5 dof]	0.27	4.62	$\delta C_9^\mu \in [-0.41, 0.17]$	$\delta C_{10}^\mu \in [0.38, 0.81]$

The theoretically-clean fit

- **Assume NP is μ-specific** (1σ, 3σ and 5σ contours)

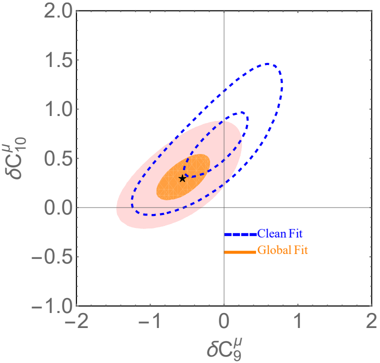


Significant changes since 2017

- SM in tension with data at 4.0σ (p-value$= 7.6 \times 10^{-5}$) from 3.5σ in 2017
- 2D fit performs better than SM at 4.6σ from 3.8σ
- C_{10}^{μ} and C_L^{μ} perform better than SM at $\sim 5\sigma$

The global fit

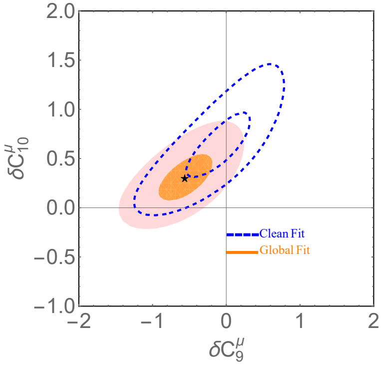
- **Assume NP is μ-specific** (1σ and 3σ contours)



Coeff.	best fit	$\chi^2_{\rm min}$	p-value	Pull$_{\rm SM}$	1σ range	3σ range
δC_9^{μ}	-0.85	106.32 [93 dof]	0.16	4.53	$[-1.06, -0.64]$	$[-1.50, -0.27]$
δC_{10}^{μ}	0.54	107.82 [93 dof]	0.14	4.37	$[0.41, 0.67]$	$[0.16, 0.94]$
δC_L^{μ}	-0.39	102.81 [93 dof]	0.23	4.91	$[-0.48, -0.31]$	$[-0.65, -0.15]$
$(\delta C_9^{\mu}, \delta C_{10}^{\mu})$	$(-0.56, 0.30)$	102.36 [92 dof]	0.22	4.58	$\delta C_9^{\mu} \in [-0.79, -0.31]$	$\delta C_{10}^{\mu} \in [0.15, 0.49]$

The global fit

- **Assume NP is μ-specific** (1σ and 3σ contours)



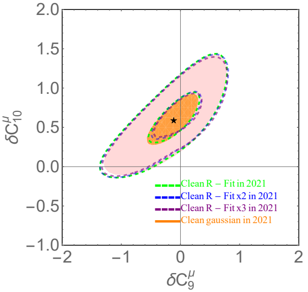
Significant changes since 2017

- Best fit shifts towards more C_9 or more LH
- 2D fit performs better than SM at 4.6σ from 4.2σ
- C_L^{μ} perform better than SM at $\sim 5\sigma$

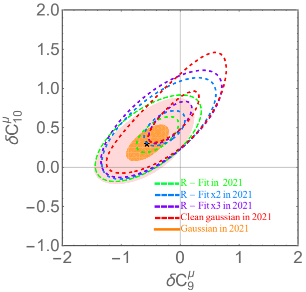
Robustness against hadronic uncertainties

- **Model-independent approach: 27** hadronic parameters
  - Treat them as nuisance parameters and obtain profile likelihoods
  - Use gaussian or flat priors (R-fit)
  - Study the impact in the fit of increasing theoretical errors
  - **Repeat for** $\times 2$ **and** $\times 3$ **th. errors**

- Theoretically-clean fit



- Global fit



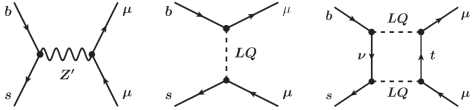
Theoretically-clean results robust w.r.t. theoretical uncertainties

Current-current interpretation!

$$\mathcal{L}_{eff} \supset \frac{C_{9(10)}}{\Lambda^2_{\rm New-Physics}}(\bar{s}\gamma^\mu P_L b)(\bar{\mu}\gamma_\mu(\gamma_5)\mu)$$

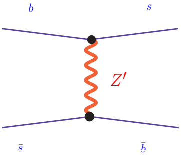
$$\Lambda_{\rm New-Physics} \sim 30 \text{ TeV!!!}$$

- UV completions: Z''s and **leptoquarks**



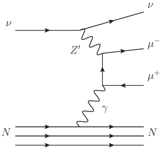
- **Extra bounds from low energy** e.g. Z'

- B_s-$\bar{B}_s$ mixing



- Requires small $Z'bs$ coupling! (e.g **MFV**)

- Neutrino trident production



- Controls $Z'\mu\mu$ coupling!

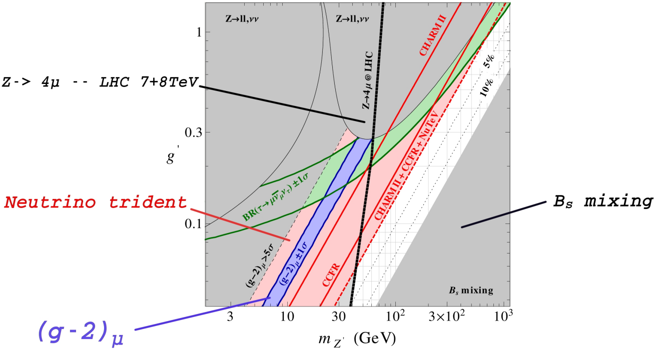
Current-current interpretation!

$$\mathcal{L}_{eff} \supset \frac{C_{9(10)}}{\Lambda^2_{\rm New-Physics}} (\bar{s}\gamma^\mu P_L b)(\bar{\mu}\gamma_\mu(\gamma_5)\mu)$$

$$\Lambda_{\rm New-Physics} \sim 30 \text{ TeV!!!}$$

- "Colored" gauged $L_\mu - L_\tau$

  Altmannshofer *et al.* PRD89(2014)095033



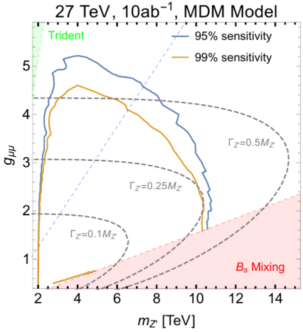
Current-current interpretation!

$$\mathcal{L}_{eff} \supset \frac{C_{9(10)}}{\Lambda^2_{\rm New-Physics}} (\bar{s}\gamma^\mu P_L b)(\bar{\mu}\gamma_\mu(\gamma_5)\mu)$$

$$\Lambda_{\rm New-Physics} \sim 30 \text{ TeV!!!}$$

- "Agnostic" simplified Z' models: $pp \to \mu^- \mu^+ X$ LHC and beyond...

Allanach *et al.* JHEP1903(2019)137



Could be far from production @ LHC (or FCC!!)

Conclusions

“Extraordinary claims require Extraordinary evidence”
– C. Sagan

1. **Theoretically-clean $b \to s\ell\ell$ observables point to NP!**
   - **Data is at odds with the SM at 4.0σ or $p -$ value $= 7.6 \times 10^{-5}$**
   - **Left-handed scenarios and with axial μ-couplings favored over the SM @ $\sim 5\sigma$**
   - Global fits favor left-handed. Interpretation sensitive to hadronic uncertainties ...
     - ★ Interplay between hadronic effects and C_9
2. **Discovery of NP?**
   - Including future **LHCb** theoretically-clean data may very soon consolidate $\gtrsim 5\sigma$

     See today Lancierini, Isidori, Owen, Serra arXiv:2104.05631 for statistical interpretations
   - What about **Belle II**? Navid K. Rad @ Moriond EW 2021