

## A combined explanation of the $B$ -decay anomalies with a single **vector leptoquark**

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Based on: JHEP12(2019)006 with C. Hati, J. Orloff and A. M. Teixeira

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## Motivation

**Deviations** in charged and neutral current  $B$ -meson decays persist

⇒ pointing towards Lepton Flavour Universality **violating** new physics

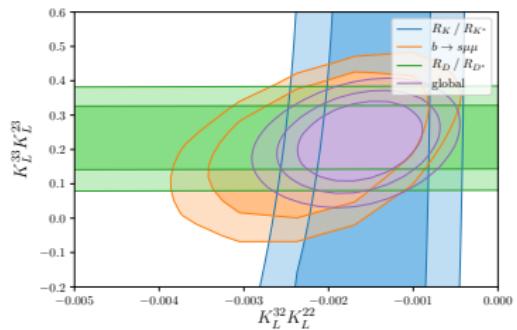
In particular: deviations in  $R_{D(*)} = \frac{\text{BR}(B \rightarrow D^{(*)} \tau \nu)}{\text{BR}(B \rightarrow D^{(*)} \ell \nu)}$  and  $R_{K(*)} = \frac{\text{BR}(B \rightarrow K^{(*)} \mu \mu)}{\text{BR}(B \rightarrow K^{(*)} ee)}$  exceed **3 $\sigma$**

### BSM Explanations:

$Z'$ , (scalar) LQs, composite Higgs, RPV SUSY...

TeV-scale  $V_1$ -leptoquark appealing NP scenario

$$\mathcal{L} \supset V_1^\mu \left( \bar{d}_L^i \gamma_\mu \mathbf{K}_L^{ik} \ell_L^k + \bar{u}_L^j V_{ji}^\dagger \gamma_\mu \mathbf{K}_L^{ik} U_{kj}^P \nu_L^j \right)$$

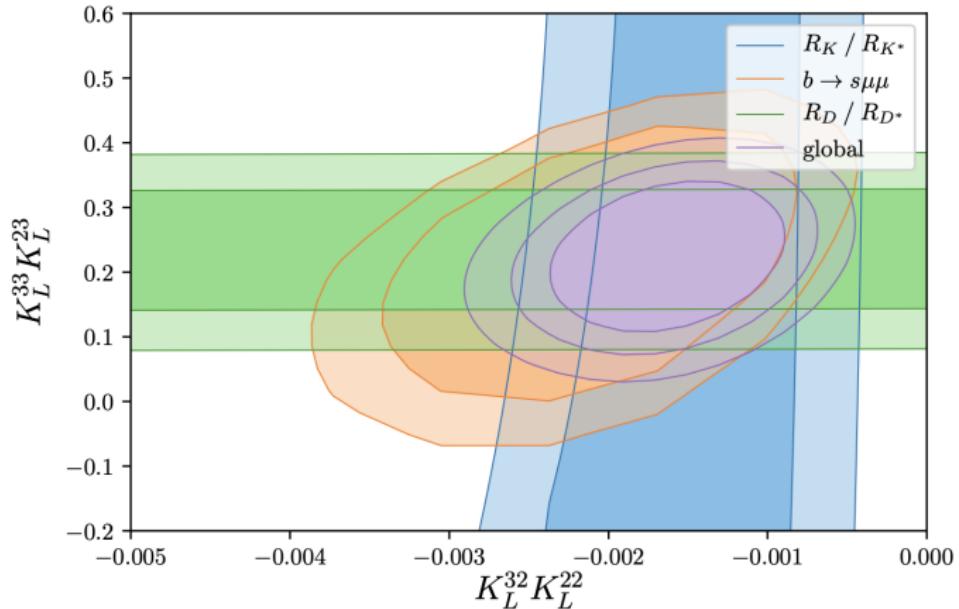


⇒ Taking  $V_1$ -model coupled to all  $(q, \ell)$ -generations in a consistent framework

Effects from RG running are crucial: A. Crivellin et. al. PRL 122, 011805

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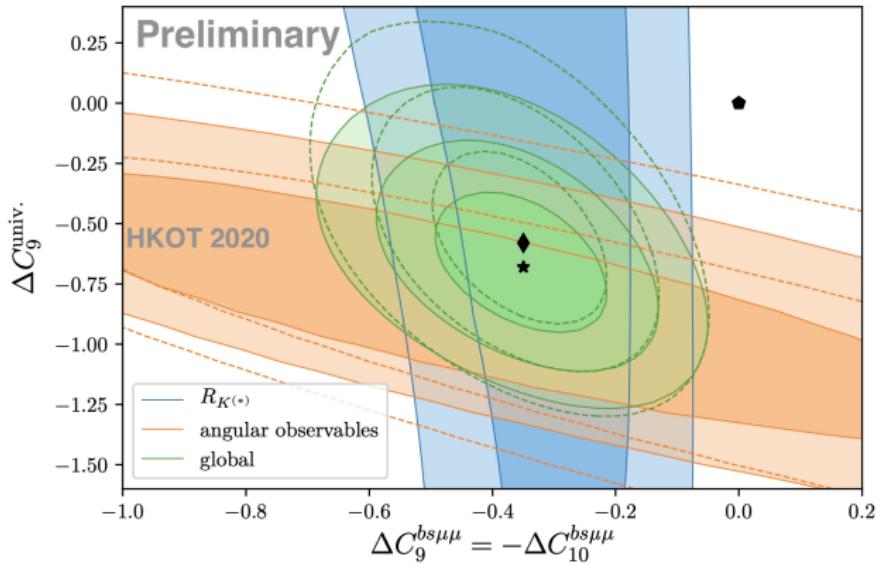
[C. Hati, JK, J. Orloff, A. M. Teixeira JHEP12(2019)006]

RG running:  $\tau$  and  $\mu$  operators mix

## More motivation in 2020

New LHCb analysis of angular observables in  $B \rightarrow K^* \mu\mu$

[PRL 125 (2020) 011802]



Dashed lines: old data  
 pentagon: SM  
 diamond: old B.F.  
 star: new B.F.

[C. Hati, JK, J. Orloff, A. M. Teixeira: to appear]

RG running-induced **universal** contribution from large  $\tau$  couplings  $\rightsquigarrow R_{D^{(*)}}$

## Non-universality from universal gauge interactions

Gauge couplings are strictly universal; how to explain **LFU Violation?**  
⇒ Only unitary *qℓ* mass missalignment is ruled out by **LFV**

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In analogy to neutrino physics, the mixing matrices get extended:

$$U_L^\ell = \begin{pmatrix} A & R \\ B & S \end{pmatrix} \begin{pmatrix} V_0 & \mathbf{0} \\ \mathbf{0} & 1 \end{pmatrix} \quad [Z. z. Xing: PLB 2008]$$

Case of  **$n = 3$**  generations:

$$\begin{pmatrix} A & R \\ B & S \end{pmatrix} = \mathcal{R}_{56}\mathcal{R}_{46}\mathcal{R}_{36}\mathcal{R}_{26}\mathcal{R}_{16}\mathcal{R}_{45}\mathcal{R}_{35}\mathcal{R}_{25}\mathcal{R}_{15}\mathcal{R}_{34}\mathcal{R}_{24}\mathcal{R}_{14}$$

$$\begin{pmatrix} V_0 & \mathbf{0} \\ \mathbf{0} & 1 \end{pmatrix} = \mathcal{R}_{23}\mathcal{R}_{13}\mathcal{R}_{12}$$

Define **semi-unitary** rectangular matrix:

$$\mathbf{K}_L^{q\ell} = (K_1, K_2) = \frac{\kappa_L}{\sqrt{2}}(A V_0, R)$$

## Non-universality from universal gauge interactions

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- ▶ Add ***n* vector-like** (VL) leptons mixing with (left-handed) SM leptons
- effective LQ- $q\text{-}\ell$  couplings  $K_L^{q\ell}$  parametrised via **non-unitary matrix**  
(from mixing with heavy states)
- ⇒ Induce **LFUV structure** in  $C_{9,10}^{ij;\ell\ell'}$  **Wilson coefficients** (tree-level)

$$C_{9,10}^{ij;\ell\ell'} = \mp \frac{\pi}{\sqrt{2}G_F \alpha V_{3j} V_{3i}^*} \frac{1}{m_{V_1}^2} K_L^{i\ell'} K_L^{j\ell*}$$

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- ⇒ Required mixing pattern could induce non-universal  $Z \rightarrow \ell\ell^{(\prime)}$  (at tree-level)
  - ↔ VL leptons have to be  **$SU(2)_L$ -doublets!!**
- ⇒  $R_{K^{(*)}}$  and  $R_{D^{(*)}}$  can be explained, tight constraints from **cLFV**, **EWPO**, colliders...

## Results: $V_1$ leptoquark & non-unitary mixing from VL leptons

Observables taken into account:

**cLFV**:  $(\mu - e)$ -conversion,  $\ell \rightarrow \ell' \gamma$ ,  $\ell \rightarrow \ell' \ell' \ell'$ ,  $\tau \rightarrow (\rho, \phi) \ell$

**LFV**:  $B_{d,s} \rightarrow \ell^\pm \ell'^\mp$ ,  $K_L \rightarrow \mu^\pm e^\mp$ ,  $B \rightarrow (K, K^*, \pi) \ell^\pm \ell'^\mp$ ,  $K \rightarrow \pi \ell^\pm \ell'^\mp$ ,  $(B \rightarrow K \nu \bar{\nu}, K \rightarrow \pi \nu \bar{\nu})$

**EWPO**:  $g_V^\ell$ ,  $g_A^\ell$ ,  $\Gamma_Z^\ell$ ,  $Z \rightarrow \ell \ell^{(\prime)}$

**LFC**:  $B_{d,s} \rightarrow \mu \mu$ ,  $B_s \rightarrow \phi \mu \mu$ ,  $B \rightarrow K^{(*)} \mu \mu$ ,  $B \rightarrow K^{(*)} ee$ ,  $B \rightarrow D^{(*)} \tau \nu$

**LFU**:  $R_{K^{(*)}}$ ,  $R_{D^{(*)}}$ , angular observables and asymmetries in  $b \rightarrow s \ell \ell$  à la  $P'_5$

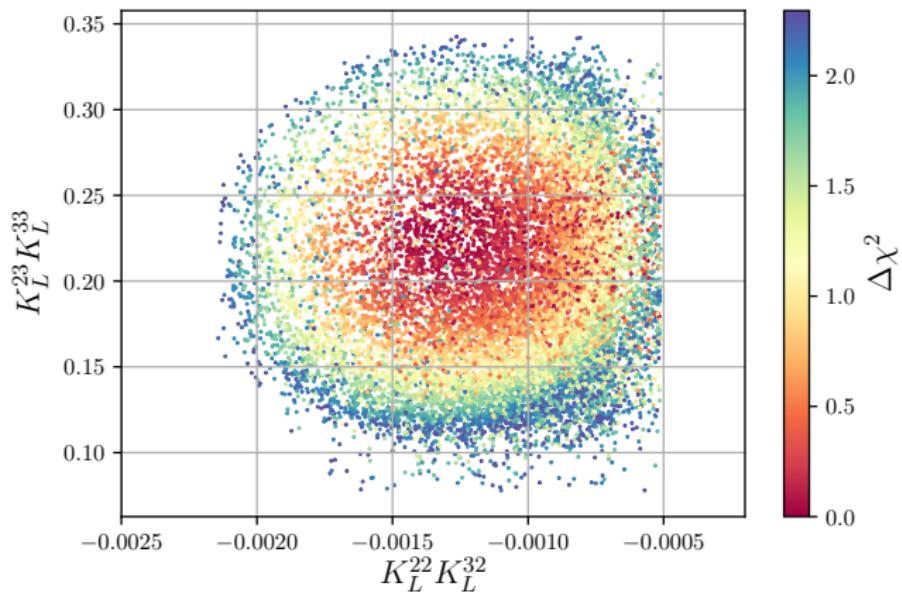
**Collider**:  $m_{V_1} \gtrsim 1.5$  TeV (as of yesterday [CMS: 1805.10228])

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Random scan, taking all SM- $(q, \ell)$ -couplings of  $V_1$  into account, complying with all constraints:

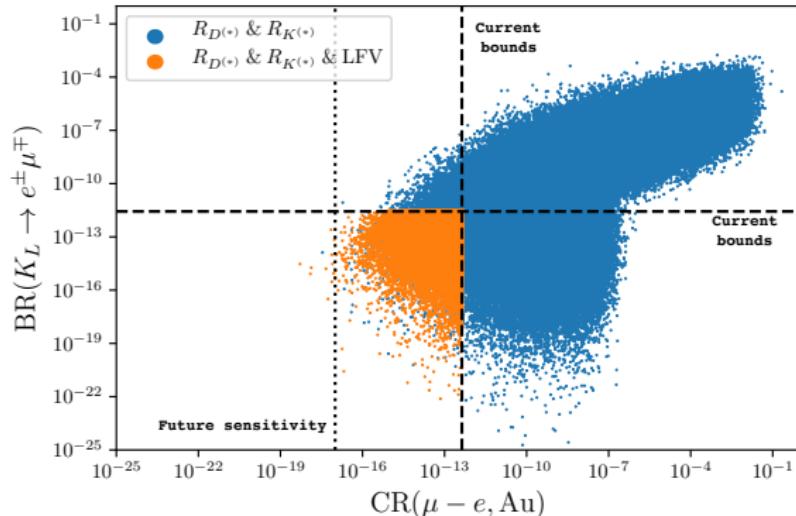
$m_{V_1} \sim 1.5$  TeV &  $n = 3$   
generations of VL leptons

[C. Hati, JK, J. Orloff, A. M. Teixeira  
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Confrontation with the most constraining observables (cLFV decays)

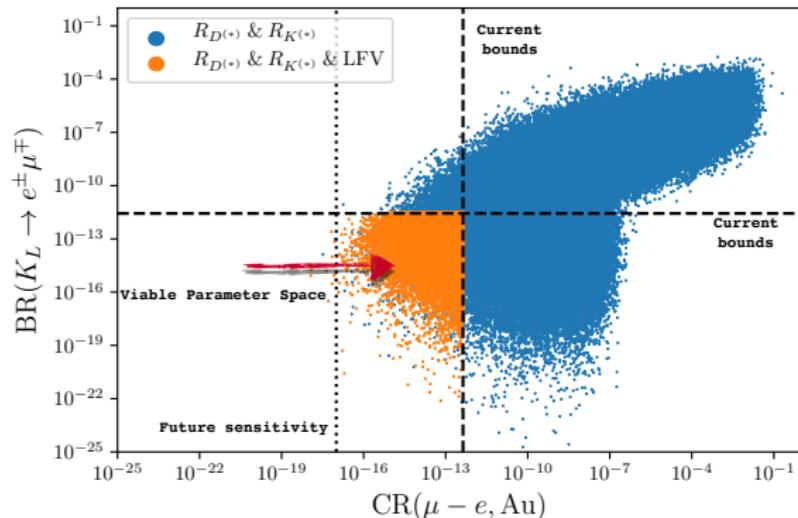


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Future limits:  $\text{CR}(\mu - e, \text{Al}) \lesssim 8 \times 10^{-17}$  (MU2E),  $\lesssim 2.6 \times 10^{-17}$  (COMET)

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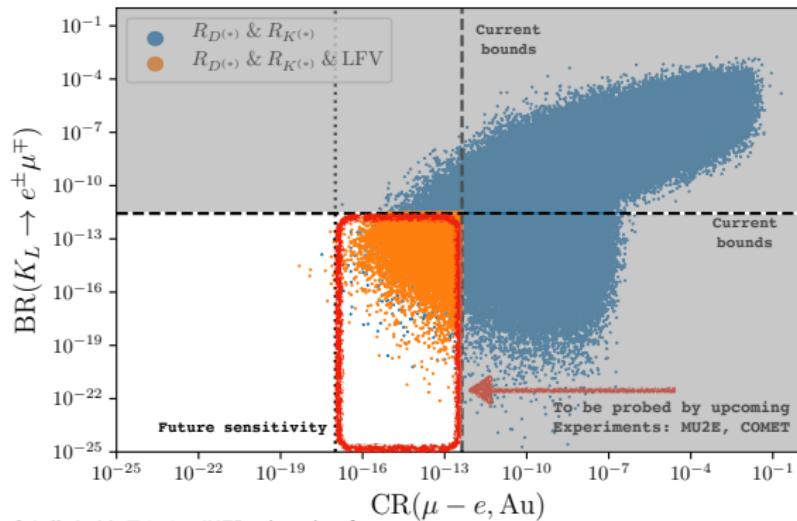


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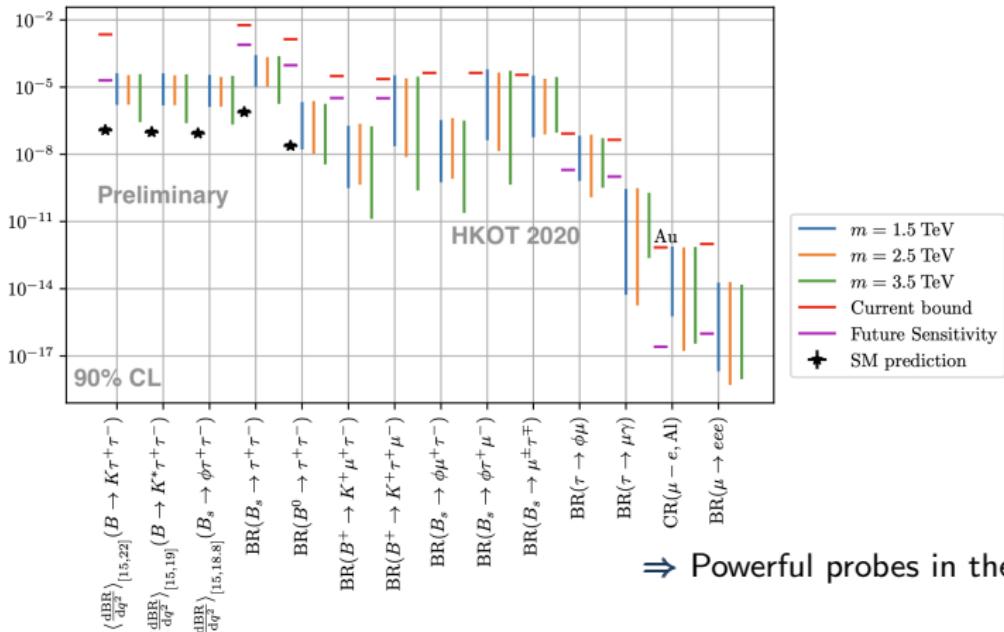
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## Prospects

BELLE II will improve sensitivities in  $b$  and  $\tau$  decays!

Fit of 9 LQ couplings:

[C. Hati, JK, J. Orloff, A. M. Teixeira: to appear]



## Conclusion

- SM extensions via  $V_1$ -leptoquark offer viable explanations for both  $B$ -decay anomalies
- **Non-unitary** coupling matrix needed:
  - ⇒ Add 3 generations of **VL leptons** (amongst other possibilities)
  - ⇒ Strong constraints from LFV meson decays & **cLFV** observables
- Large region of the **parameter space** to be probed in the near **future!**



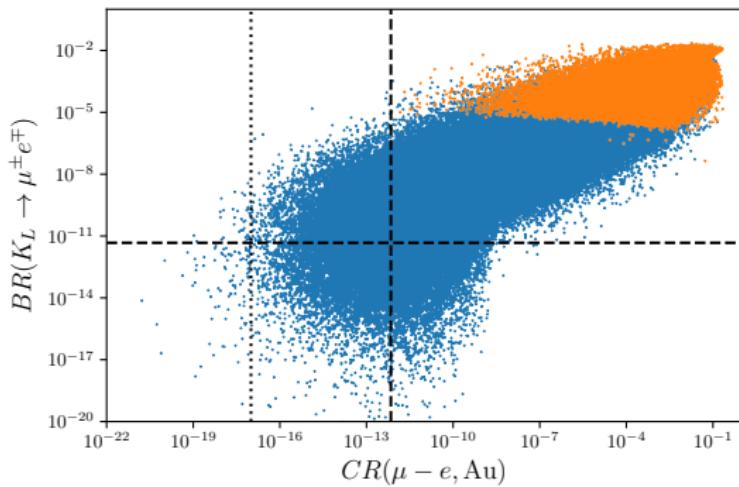
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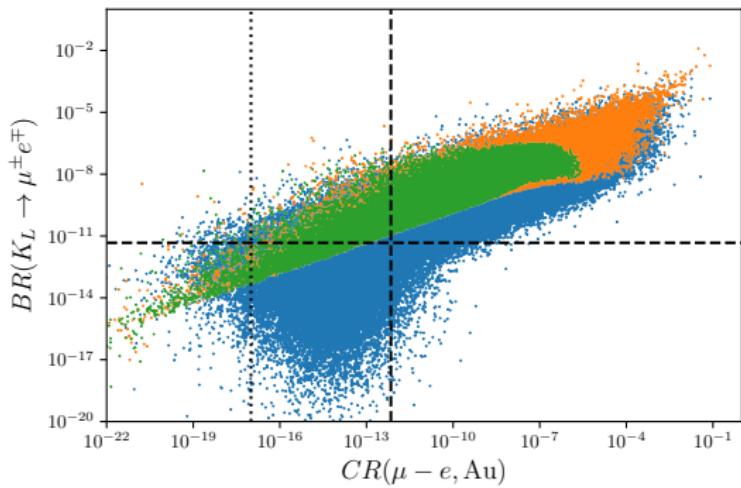


## Backup



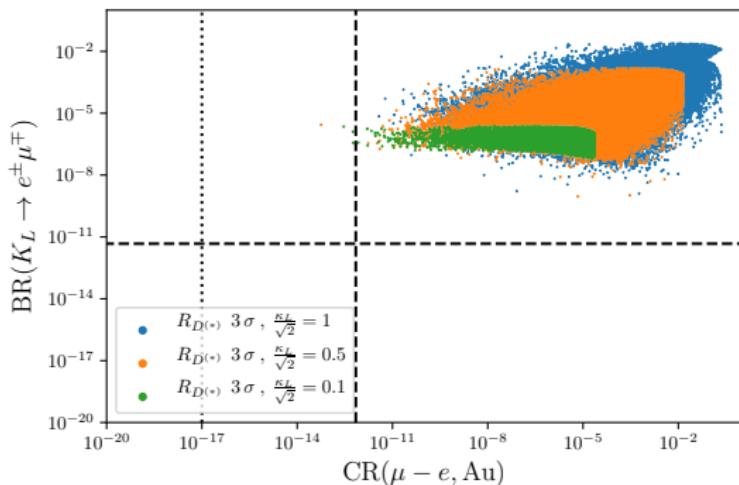
Yellow points: 3 VL singlets fitting  $R_{D^{(*)}}$  and complying with  $Z$  decays, Blue points: fitting  $R_{D^{(*)}}$  but ruled out by  $Z$   
 $m_{V_1} \sim 1.5$  TeV

## Backup



All: 3 VL singlets, fitting  $R_{K(*)}$ , yellow: complying with  $Z$ , green: complying with all other LFV  
 $m_{V_1} \sim 15$  TeV

## Backup



$m_{V_1} \sim 1.5 \text{ TeV}$ , no additional fermions  $\rightarrow$  unitary parametrisation. Different values for the gauge coupling are shown.