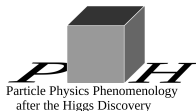


Status of New Physics in Lepton Flavour Universality Violating B Decays

Monika Blanke



KEK theory seminar
February 12, 2019

Recent anomalies in B meson decays



- 1 3.8σ anomaly in **semi-tauonic B decays**, exhibiting lepton flavour universality violation
- 2 various *consistent* $2 - 3\sigma$ deviations in **$b \rightarrow s\mu^+\mu^-$ transitions**, leading to a $\sim 5\sigma$ tension in the global fit

Outline

- 1 Flavour basics in the Standard Model
- 2 Status of the $b \rightarrow c\tau\nu$ anomaly
- 3 Semileptonic $b \rightarrow s$ transitions
- 4 A 5D warped Pati-Salam model



Flavour in the Standard Model (SM)

- **Quark flavour violation** described by **CKM matrix**

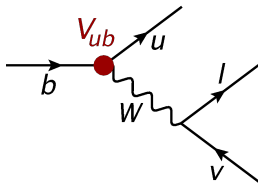
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V_{\text{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- No flavour violating decays in the SM lepton sector
- **Lepton flavour universality** only violated by the (small) lepton masses

$$m_e \ll m_\mu \ll m_\tau$$

Precision determination of CKM elements

Tree level decays: flavour changing **charged current** interactions

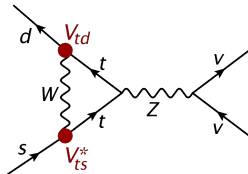
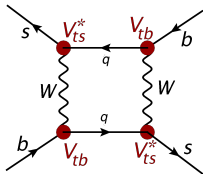


- direct sensitivity to relevant CKM element
- small impact of new physics contributions

➤ **model-independent** determination of CKM matrix as a **standard candle** of the SM

Flavour changing neutral current processes

Loop-induced transitions:



strongly suppressed in the SM

- loop factor
- CKM hierarchy
- chiral structure
- GIM mechanism (CKM unitarity)

➤ high sensitivity to **BSM** contributions

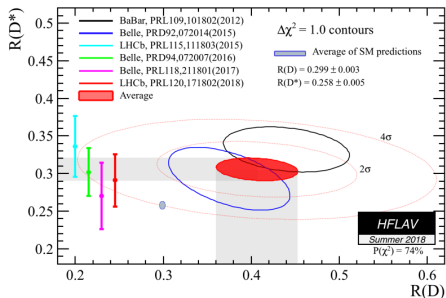
$b \rightarrow c\tau\nu$ – the anomalous trees



The $\mathcal{R}(D^{(*)})$ anomaly

Test of lepton flavour universality in semi-leptonic B decays

$$\mathcal{R}(D^{(*)}) = \frac{\text{BR}(B \rightarrow D^{(*)}\tau\nu)}{\text{BR}(B \rightarrow D^{(*)}\ell\nu)} \quad (\ell = e, \mu)$$



- **theoretically clean**, as hadronic uncertainties largely cancel in ratio
- measurements by BaBar, Belle, and LHCb (so far $\mathcal{R}(D^*)$ only)
- **3.8σ tension** between HFLAV fit and SM value
- (qualitatively) supported by measurement of $\mathcal{R}(J/\psi)$ (LHCb)

Related $b \rightarrow c\tau\nu$ observables

- ratio of baryonic decay rates

$$\mathcal{R}(\Lambda_c) = \frac{\text{BR}(\Lambda_b \rightarrow \Lambda_c \tau \nu)}{\text{BR}(\Lambda_b \rightarrow \Lambda_c \ell \nu)} \quad (\ell = e, \mu)$$

- longitudinal D^* polarisation

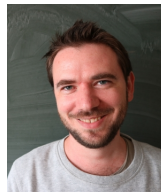
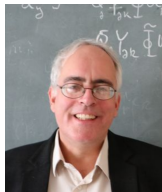
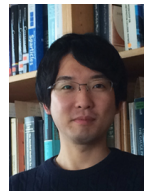
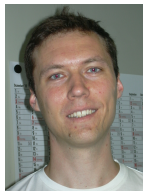
$$F_L(D^*) = \frac{\Gamma(B \rightarrow D_L^* \tau \nu)}{\Gamma(B \rightarrow D^* \tau \nu)} \quad \begin{array}{l} \text{Belle : } 0.60 \pm 0.08 \pm 0.035 \\ \text{SM : } 0.46 \pm 0.04 \end{array}$$

- τ polarisation asymmetries

$$P_\tau(D^{(*)}) = \frac{\Gamma(B \rightarrow D^{(*)} \tau^{\lambda=+1/2} \nu) - \Gamma(B \rightarrow D^{(*)} \tau^{\lambda=-1/2} \nu)}{\Gamma(B \rightarrow D^{(*)} \tau \nu)}$$

- $\text{BR}(B_c \rightarrow \tau \nu)$ – particularly sensitive to scalar contributions

The Crew



MB, CRIVELLIN, DE BOER, KITAHARA, MOSCATI, NIERSTE, NIŠANDŽIĆ
ARXIV:1811.09603

A closer look at $B_c \rightarrow \tau\nu$

Constraints on $\text{BR}(B_c \rightarrow \tau\nu)$ advocated in the literature:

- measured total B_c lifetime \triangleright **$\text{BR}(B_c \rightarrow \tau\nu) < 30\%$**

ALONSO, GRINSTEIN, MARTIN CAMALICH (2016)

caveats of τ_{B_c} theory prediction

BENEKE, BUCHALLA (1996)

- large m_c dependence (LO QCD calculation, $1.4 \text{ GeV} < m_c < 1.6 \text{ GeV}$)
- based on heavy quark expansion and non-rel. QCD, but B_c decays dominantly through charm decay

A closer look at $B_c \rightarrow \tau\nu$

Constraints on $\text{BR}(B_c \rightarrow \tau\nu)$ advocated in the literature:

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ALONSO, GRINSTEIN, MARTIN CAMALICH (2016)

- searches for $B_{u,c} \rightarrow \tau\nu$ at LEP1 \triangleright **$\text{BR}(B_c \rightarrow \tau\nu) < 10\%$**

AKERROYD, CHEN (2017)

caveats of theory interpretation

- relies crucially on ratio of $b \rightarrow B_c$ vs. $b \rightarrow B_u$ fragmentation functions
- Tevatron and LHC determinations of f_c/f_u not applicable to LEP (hadron collisions vs. Z peak observables)

A closer look at $B_c \rightarrow \tau\nu$

Constraints on $\text{BR}(B_c \rightarrow \tau\nu)$ advocated in the literature:

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ALONSO, GRINSTEIN, MARTIN CAMALICH (2016)
- searches for $B_{u,c} \rightarrow \tau\nu$ at LEP1 \triangleright **$\text{BR}(B_c \rightarrow \tau\nu) < 10\%$**
AKERROYD, CHEN (2017)

Critical assessment:

- more refined studies needed
- our conservative bound: **$\text{BR}(B_c \rightarrow \tau\nu) < 60\%$**

MB, CRIVELLIN, DE BOER, KITAHARA, MOSCATI, NIERSTE, NIŠANDŽIĆ (2018)

Effective Hamiltonian

New Physics above B meson scale described model-independently by

$$\mathcal{H}_{\text{eff}}^{\text{NP}} = 2\sqrt{2}G_F V_{cb} \left[(1 + C_V^L) O_V^L + C_S^R O_S^R + C_S^L O_S^L + C_T O_T \right]$$

with the vector, scalar and tensor operators

$$O_V^L = (\bar{c}\gamma^\mu P_L b) (\bar{\tau}\gamma_\mu P_L \nu_\tau)$$

$$O_S^R = (\bar{c}P_R b) (\bar{\tau}P_L \nu_\tau)$$

$$O_S^L = (\bar{c}P_L b) (\bar{\tau}P_L \nu_\tau)$$

$$O_T = (\bar{c}\sigma^{\mu\nu} P_L b) (\bar{\tau}\sigma_{\mu\nu} P_L \nu_\tau)$$

Note: $(\bar{c}\gamma^\mu P_R b) (\bar{\tau}\gamma_\mu P_L \nu_\tau)$ not generated at dimension-six level in the $SU(2)_L \times U(1)_Y$ -invariant theory

One-dimensional scenarios

single particle scenarios

 C_V^L

left-handed W' boson

left-handed $SU(2)_L$ -singlet vector leptoquark (LQ)

scalar $SU(2)_L$ -triplet and/or -singlet LQ (LH couplings only)

 C_S^R

charged Higgs (2HDM-II at large $\tan\beta$)

$SU(2)_L$ -doublet vector LQ

 C_S^L

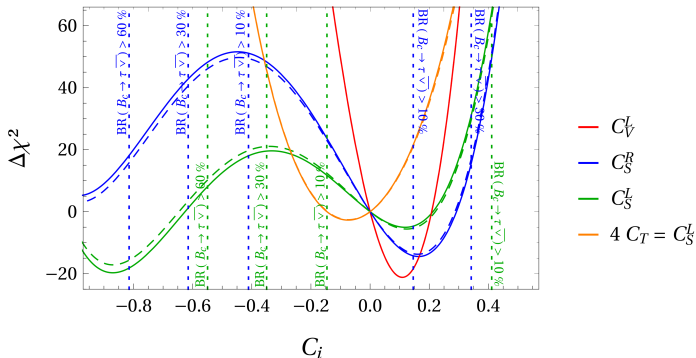
charged Higgs with generic flavor structure

 $C_S^L = 4C_T$

scalar $SU(2)_L$ -doublet (relation at NP scale, modified by RG effects)

One-dimensional fit results

MB, CRIVELLIN, DE BOER, KITAHARA, MOSCATI, NIERSTE, NIŠANDŽIĆ (2018)



- best fit for $C_V^L \sim 0.11$
- small impact of $F_L(D^*)$ measurement (solid vs. dashed)
- large impact of $\text{BR}(B_c \rightarrow \tau\nu)$ on scalar scenarios

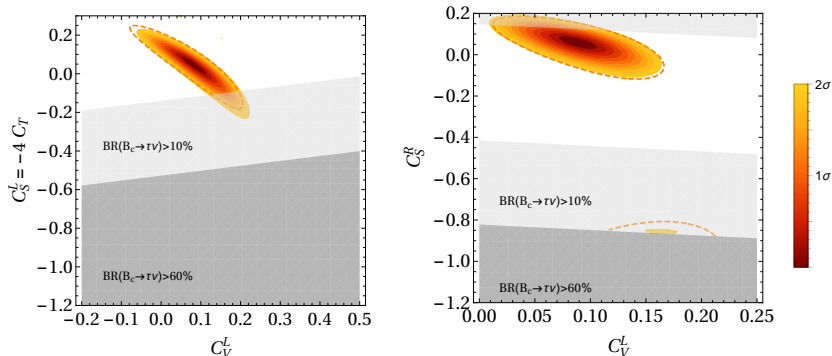
Two-dimensional scenarios

single particle scenarios

$(C_V^L, C_S^L = -4C_T)$	SU(2) _L -singlet scalar LQ
(C_V^L, C_S^R)	SU(2) _L -singlet vector LQ
(C_S^R, C_S^L)	charged Higgs
$(\text{Re}[C_S^L = 4C_T],$ $\text{Im}[C_S^L = 4C_T])$	scalar SU(2) _L -doublet LQ with CP-violating couplings

Two-dimensional fit results (I)

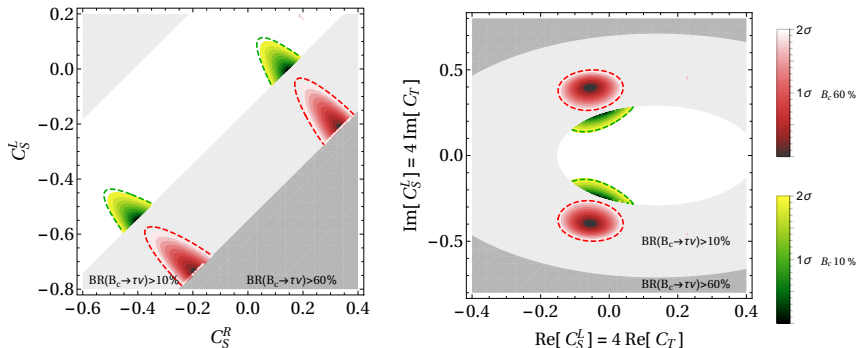
MB, CRIVELLIN, DE BOER, KITAHARA, MOSCATI, NIERSTE, NIŠANDŽIĆ (2018)



- good fit for both $(C_V^L, C_S^L = -4C_T)$ and (C_V^L, C_S^R)
- small impact of $\text{BR}(B_c \rightarrow \tau\nu)$ constraint

Two-dimensional fit results (II)

MB, CRIVELLIN, DE BOER, KITAHARA, MOSCATI, NIERSTE, NIŠANDŽIĆ (2018)



- very good fit for (C_S^R, C_S^L) , but only allowed for $BR(B_c \rightarrow \tau\nu) < 60\%$
- good fit for $(C_S^L = 4C_T)$, unless $BR(B_c \rightarrow \tau\nu) < 10\%$ is imposed

The $\Lambda_b \rightarrow \Lambda_c \tau \nu$ sum rule

MB, CRIVELLIN, DE BOER, KITAHARA, MOSCATI, NIERSTE, NIŠANDŽIĆ (2018)

From the phenomenological expressions for $\mathcal{R}(D^{(*)})$ and $\mathcal{R}(\Lambda_c)$, we derive an **approximate sum rule**:

$$\frac{\mathcal{R}(\Lambda_c)}{\mathcal{R}_{\text{SM}}(\Lambda_c)} \simeq 0.262 \frac{\mathcal{R}(D)}{\mathcal{R}_{\text{SM}}(D)} + 0.738 \frac{\mathcal{R}(D^*)}{\mathcal{R}^{\text{SM}}(D^*)} + \mathcal{O}(10^{-2})$$

- enhancement of $\mathcal{R}(D^{(*)})$ implies $\mathcal{R}(\Lambda_c) > \mathcal{R}_{\text{SM}}(\Lambda_c) = 0.33 \pm 0.01$
- model-independent prediction from current $\mathcal{R}(D^{(*)})$ data:

$$\mathcal{R}(\Lambda_c) = 0.41 \pm 0.02_{\mathcal{R}(D^{(*)})} \pm 0.01_{\text{form factors}}$$

- **experimental cross-check of $\mathcal{R}(D^{(*)})$ anomaly**

Summary: Where do we stand in $b \rightarrow c\tau\nu$?

MB, CRIVELLIN, DE BOER, KITAHARA, MOSCATI, NIERSTE, NIŠANDŽIĆ (2018)

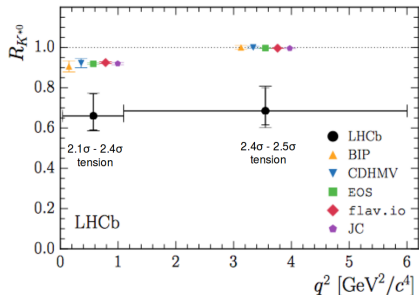
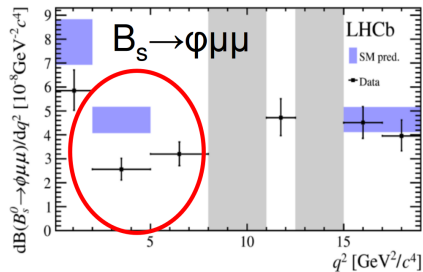
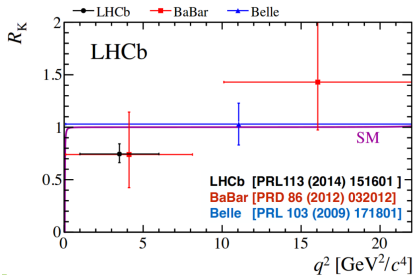
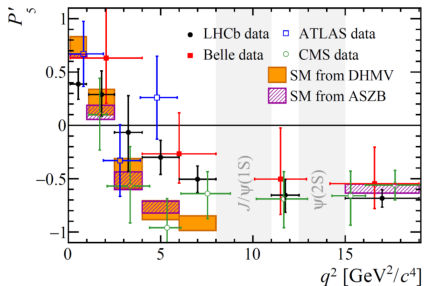
- updated 1D and 2D fits, including recent $F_L(D^*)$ measurement
 - 1D: best fit for $C_V^L \neq 0$
 - 2D: decent fit for all scenarios
 - large impact of $\text{BR}(B_c \rightarrow \tau\nu)$ limit on scalar scenarios

- $\Lambda_b \rightarrow \Lambda_c\tau\nu$ provides experimental cross-check of $\mathcal{R}(D^{(*)})$ anomaly

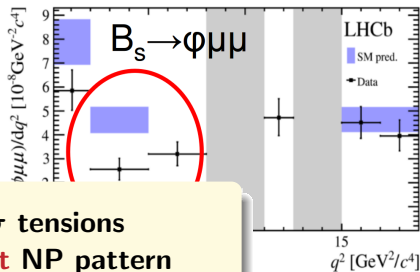
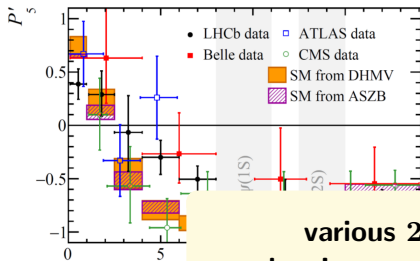
- [not shown here due to lack of time] polarisation observables well suited to distinguish among different EFT scenarios
 - requires better understanding of form factors

$b \rightarrow s\mu\mu$ – the anomalous penguins

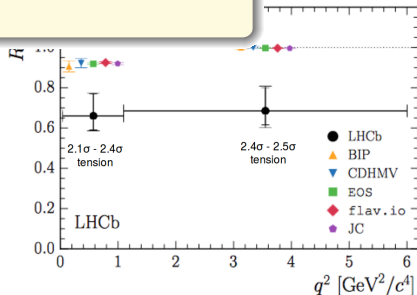
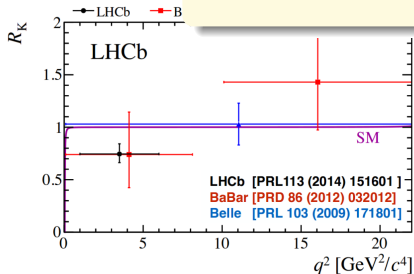
The $b \rightarrow s \mu^+ \mu^-$ transitions and LFU



The $b \rightarrow s \mu^+ \mu^-$ transitions and LFU



various 2 – 3 σ tensions
 showing **consistent NP** pattern

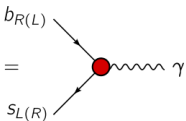


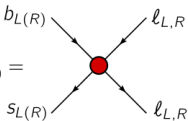
Theoretical description

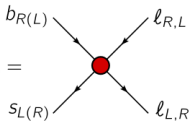
$b \rightarrow sl^+\ell^-$ and $b \rightarrow s\gamma$ transitions described by effective Hamiltonian

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb}^* V_{ts} \frac{e^2}{16\pi^2} \sum_i (C_i \mathcal{O}_i + C'_i \mathcal{O}'_i) + h.c.$$

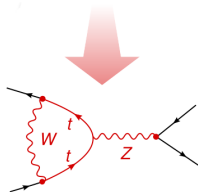
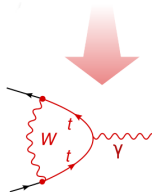
where the operators most sensitive to new physics are

$$\mathcal{O}_7^{(l)} =$$


$$\mathcal{O}_{9,10}^{(l)} =$$


$$\mathcal{O}_{S,P}^{(l)} =$$


SM:



Sensitivity to Wilson coefficients

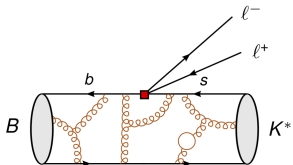
Complementary sensitivity

	$C_7^{(')}$	$C_9^{(')}$	$C_{10}^{(')}$	$C_{S,P}^{(')}$
$B \rightarrow X_s \gamma$	X			
$B \rightarrow K^* \gamma$	X			
$B \rightarrow X_s \ell^+ \ell^-$	X	X	X	
$B \rightarrow K^{(*)} \ell^+ \ell^-$	X	X	X	
$B_s \rightarrow \phi \ell^+ \ell^-$	X	X	X	
$B_s \rightarrow \mu^+ \mu^-$			X	X

- different observables constrain different operators
- **global analysis** can be used to resolve ambiguities
- apparent deviation from the SM in one observable can be **cross-checked** in related modes

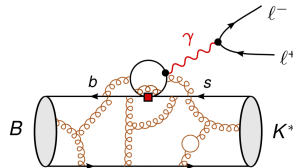
Hadronic uncertainties in $B \rightarrow K^{(*)} \mu^+ \mu^-$

$B \rightarrow K^*$ form factors



- from lattice QCD and light-cone sum rules
- systematic improvements possible

non-factorisable corrections



- “charm loops” at low q^2 and broad $c\bar{c}$ resonances
- dominant uncertainty, no systematic theory description

➤ **construct observables in which these uncertainties cancel**

Clean observables

Optimised observables P_i, P'_i

MATIAS ET AL. (2012)

- describe **angular distribution** in $B \rightarrow K^* \mu^+ \mu^-$
- designed to be **form-factor-free** at leading order
- still susceptible to **non-factorisable corrections**

Lepton flavour universality (LFU) ratios

HILLER, KRÜGER (2003)

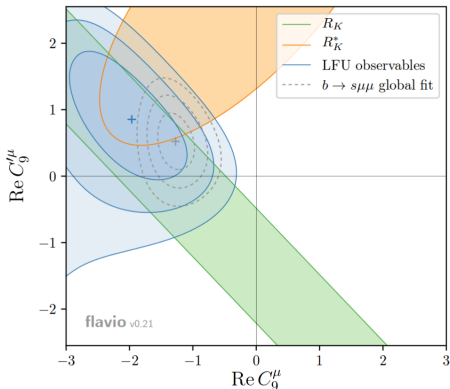
$$\mathcal{R}(K^{(*)}) = \frac{\text{BR}(B \rightarrow K^{(*)} \mu^+ \mu^-)}{\text{BR}(B \rightarrow K^{(*)} e^+ e^-)} \quad (\text{and similar for other f. s. mesons})$$

- theoretically **extremely clean**

Global analysis

ALTMANNSHOFER, STANGL, STRAUB (2017)

see also CAPDEVILA ET AL. (2017)

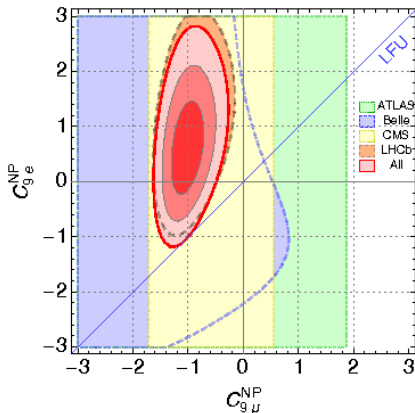


- consistent fit for $C_9^{\text{NP}} \simeq -1$, non-zero C_9^{NP} , C_{10}^{NP} possible
 $\sim 5\sigma$ deviation from SM!

Yet not quite global experimentally

CAPDEVILA ET AL. (2017)

see also ALTMANNSHOFER, STANGL, STRAUB (2017)



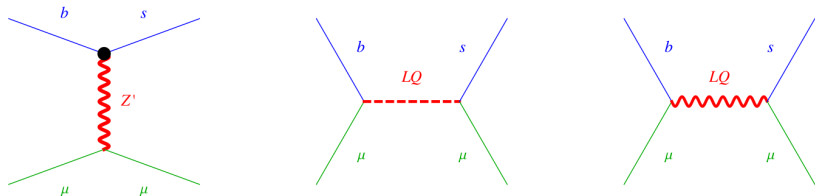
➤ dominated by LHCb – we need **independent cross-check!**

Who ordered that?

ALTMANNSHOFER, STRAUB (2013); HILLER, SCHMALTZ (2014)
 ALTMANNSHOFER ET AL. (2014); ALTMANNSHOFER, CARENA, CRIVELLIN (2016)
 D'AMICO ET AL. (2017); DI CHIARA ET AL. (2017)

...

The usual suspects: Z' and leptoquarks



- tree level NP competing with SM one-loop diagrams
- constraints from $B_s - \bar{B}_s$ mixing can be accommodated
- potential relation to $(g - 2)_\mu$ anomaly

Loop induced NP?

Large C_9^{NP} as model-killer

ALTMANNSHOFER, STRAUB (2013)

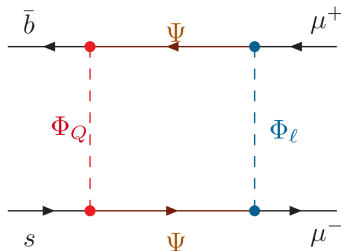
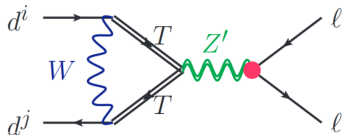
- new contributions to Z penguin (e. g. in the MSSM) don't yield required NP pattern – also no LFU violation

Viable setups

- Z' penguin effect

BÉLANGER, DELAUNAY, WESTHOFF (2015)
KAMENIK, SOREQ, ZUPAN (2017)

- box contribution GRIPAIS, NARDECCHIA, RENNER (2015); ARNAN ET AL. (2016)



A combined resolution of the B decay anomalies?

- several attempts to attribute the B decay anomalies to a *common* NP origin

BARBIERI, MURPHY, SENIA (2016); CRIVELLIN, MÜLLER, OTA (2017)
 BECIREVIC, DORSNER, FAJFER, FAROUGHY, KOSNIK, SUMENSARI (2018)
 DI LUZIO, GRELJO, NARDECCHIA (2017); CALIBBI, CRIVELLIN, LI (2017)
 BORDONE, CORNELLA, FUENTES-MARTIN, ISIDORI (2017); MARZOCCA (2018) ...

- $SU(2)_L$ singlet vector leptoquark appears most promising:
 - evades stringent constraints from B_s mixing and $b \rightarrow s\nu\bar{\nu}$
 - B_c life-time under control

Model building challenges

- identify UV origin of such vector LQ
- generate flavour non-universal LQ couplings
- avoid re-introduction of constraints due to additional particles present in UV-complete model

Let's go model-building!



The Pati-Salam vector leptoquark

Prime BSM candidate for simultaneous explanation:

$SU(2)_L$ singlet vector leptoquark with LH couplings to fermions

- no tree level contributions to $B_s - \bar{B}_s$ mixing and $b \rightarrow s\nu\bar{\nu}$ transitions
- purely left-handed coupling structure favoured by
 - global $b \rightarrow s\mu^+\mu^-$ fits
 - total B_c lifetime
 - $B \rightarrow D\tau\nu$ differential rate

Towards UV-complete model

Vector LQ arising from Pati-Salam gauge group

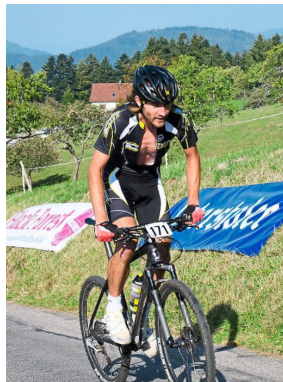
PATI, SALAM (1974)

$$SU(4) \times SU(2)_L \times SU(2)_R$$

has the right gauge quantum numbers!

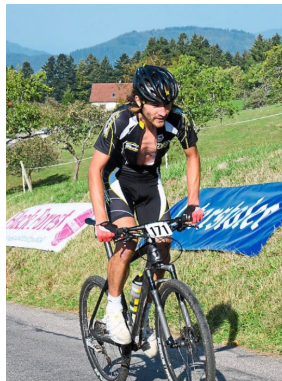
Challenge: flavour non-universal couplings to fermions

The Crew



MB, CRIVELLIN – PRL 121 (2018) NO.1, 011801

The Crew



MB, CRIVELLIN – PRL 121 (2018) NO.1, 011801

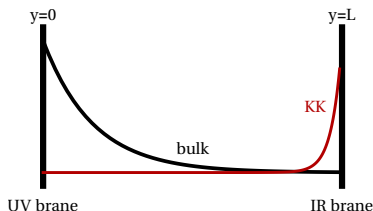
Pati-Salam in the Randall-Sundrum background

Idea: embed Pati-Salam model into the 5D Randall-Sundrum space-time MB, CRIVELLIN (2018)

$$ds^2 = e^{-2ky} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2 \quad 0 \leq y \leq L$$

RANDALL, SUNDRUM (1999)

- extra space-time coordinate y confined to interval $0 \leq y \leq L$, and warped by e^{-2ky} factor
- 4D Kaluza-Klein (KK) decomposition
 - towers of massive KK modes localized near IR brane
 - massless zero modes depending on boundary conditions
 - identified with SM particles



Gauge symmetry breaking pattern

Two step symmetry breaking pattern

MB, CRIVELLIN (2018)

- 1 Pati-Salam gauge symmetry in the 5D bulk, broken by **boundary conditions on the UV brane**

$$SU(4) \times SU(2)_L \times SU(2)_R \rightarrow SU(3)_c \times SU(2)_L \times U(1)_Y$$

- 2 **SM Higgs confined to the UV brane** induces EW symmetry breaking

$$SU(2)_L \times U(1)_Y \rightarrow U(1)_{\text{em}}$$

- Higgs decoupled from KK modes at IR brane
- stringent EW precision constraints are evaded
- Yukawa couplings need to respect SM gauge symmetry only
- *but*: usual RS solution to gauge and flavour hierarchy problems lost

Fermion sector

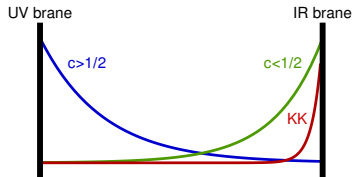
- fermions as 5D bulk fields in complete PS representations

$$\begin{pmatrix} u_L^1 & u_L^2 & u_L^3 & \nu_L \\ d_L^1 & d_L^2 & d_L^3 & \ell_L \end{pmatrix} \sim (4, 2, 1) \quad \begin{pmatrix} u_R^1 & u_R^2 & u_R^3 & \nu_R \\ d_R^1 & d_R^2 & d_R^3 & \ell_R \end{pmatrix} \sim (4, 1, 2)$$

➤ massless zero modes correspond to SM fermions

- zero mode localization along extra dimension y depends exponentially on 5D bulk mass parameter $c = m_{5D}/k$

➤ non-universal couplings to KK modes



B anomalies require

- hierarchical localization of LH fermions: $c_{L1} > c_{L2} > c_{L3}$
- RH fermions localized at UV brane

The 4D composite dual

AdS/CFT correspondence: dual 4D composite model

- elementary sector with SM gauge group
- elementary Higgs field
- composite sector with Pati-Salam global symmetry
- left-handed fermions partially composite – linear mixing of SM fermions with composite resonances: $0 \sim s_1^{q,\ell} \ll s_2^{q,\ell} \ll s_3^{q,\ell} \sim 1/\sqrt{2}$
- right-handed fermions (mostly) elementary

The 4D composite dual

AdS/CFT correspondence: dual 4D composite model

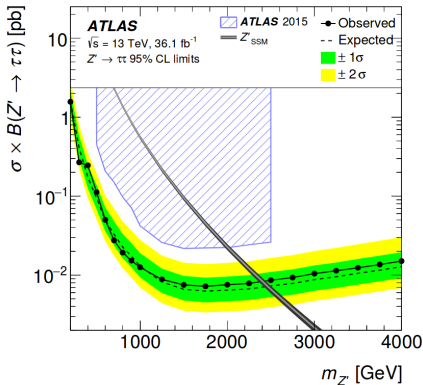
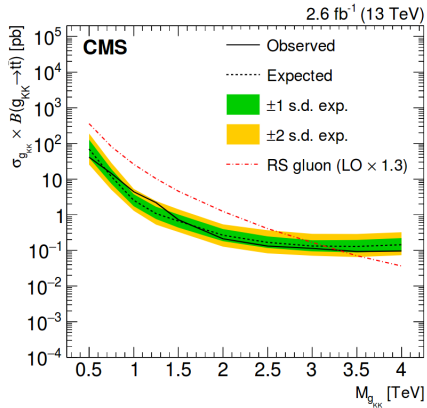
- elementary sector with SM gauge group
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- right-handed fermions (mostly) elementary

Simplified model: keep only SM fields + lowest-lying KK modes

- common mass scale M_{KK} for all new particles
- massive vector resonances for entire PS gauge group
- massive vectorlike fermions that mix with SM fermions

LHC constraints

strongest constraints from searches for $t\bar{t}$ and $\tau\bar{\tau}$ resonances



➤ for our model: $M_{KK} \geq 3$ TeV

Flavour alignment

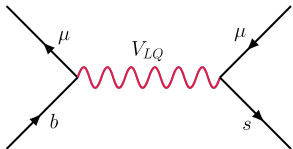
- generically, KK modes of gluons, $B - L$ gauge boson and W_L^3 mediate tree level FCNCs
 - reintroduces problematic contributions to meson mixings and $b \rightarrow s\nu\bar{\nu}$
- avoided by imposing flavour alignment between elementary-composite mixing (=5D bulk masses) and Y_d
 - no tree level FCNCs in the down sector
 - relevant tree level contribution to $D^0 - \bar{D}^0$ mixing (CKM)
- resulting leptoquark coupling matrix

$$\Gamma_{d_i l_j}^{LQ,L} = \frac{ig_s^*}{\sqrt{2}} \begin{pmatrix} 0 & 0 & 0 \\ 0 & s_2^q s_2^\ell c_\ell & s_2^q s_2^\ell s_\ell \\ 0 & -s_3^q s_3^\ell s_\ell & s_3^q s_3^\ell 2c_\ell \end{pmatrix}_{ij}$$

$u_i \nu_j$ coupling includes additional CKM rotation

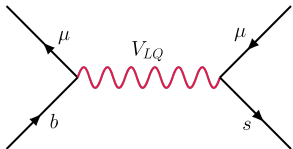
Important tree level effects

$$b \rightarrow s \mu^+ \mu^-$$

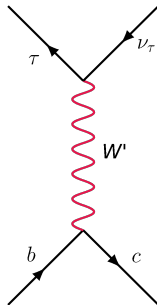
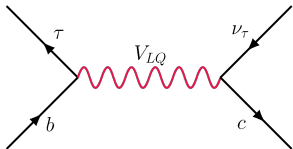


Important tree level effects

$$b \rightarrow s \mu^+ \mu^-$$

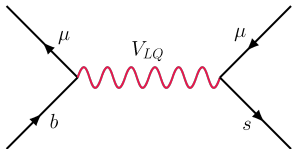


$$b \rightarrow c \tau \nu$$

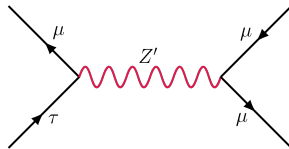


Important tree level effects

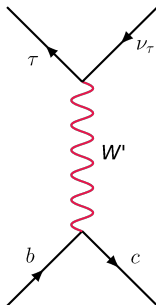
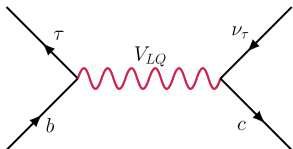
$$b \rightarrow s\mu^+\mu^-$$



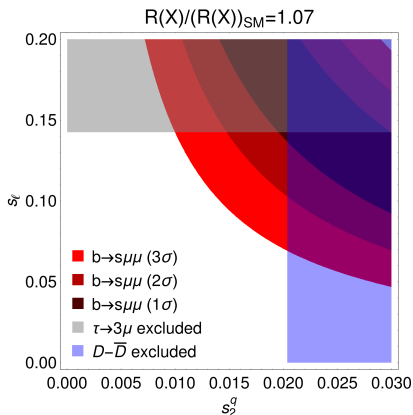
$$\tau \rightarrow 3\mu$$



$$b \rightarrow c\tau\nu$$



Can we resolve the B decay anomalies?



MB, CRIVELLIN (2018)

Benchmark point:

$$M = 3 \text{ TeV}$$

$$s_2^\ell = 0.2$$

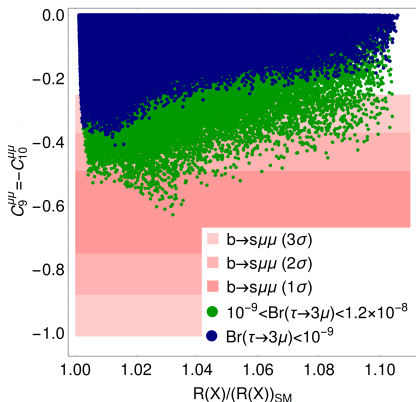
$$s_3^\ell = 1/\sqrt{2}$$

$$s_3^q = \sqrt{3}/2$$

- $b \rightarrow s\mu^+\mu^-$ data can be explained at the 1σ level
- $\mathcal{R}(X)/\mathcal{R}(X)_{SM} \approx 1.07$ (with $X = D, D^*, J/\Psi$)

Can we resolve the B decay anomalies?

MB, CRIVELLIN (2018)



Parameter scan:

$$M = 3 \text{ TeV}$$

$$0.3 < s_3^q < \sqrt{3}/2$$

$$0 < s_2^q < 0.2$$

$$0.3 < s_3^\ell < \sqrt{3}/2$$

$$0 < s_2^\ell < 0.2$$

$$0 < s_\ell < 0.3$$

imposing $D - \bar{D}$ mixing constraint

- $b \rightarrow s\mu^+\mu^-$ tension can be resolved
- $b \rightarrow c\tau\nu$ tension can be ameliorated
- observable rate for $\tau \rightarrow 3\mu$ predicted

Conclusions

- **B decay anomalies** still give one of the best hints for BSM physics
- theoretically appealing common solution by **$SU(2)_L$ singlet vector leptoquark**
- possible UV-completion in terms of **Pati-Salam model in the Randall-Sundrum background**