A warped Pati-Salam model for the B decay anomalies

MB & A. Crivellin – arXiv:1801.xxxxx

Monika Blanke

Karlsruher Institut für Technologie

ZPW 2018 - Flavours: light, heavy, and dark

Zürich – January 15, 2018

B decay anomalies from the BSM perspective

B decay measurements

- 4.1σ deviation in $b \to c\tau\nu$ decays
- $\sim 5\sigma$ anomaly in $b \to s\mu^+\mu^-$ transitions

Implications for BSM physics

- new particles at the TeV scale
- new source of lepton flavour universality violation
- yet need to comply with stringent constraints from
  - direct LHC searches
  - Higgs and electroweak precision constraints
  - flavour observables like B_s mixing, $b \to s\nu\bar{\nu}$ etc.

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 $b \to s\nu\bar{\nu}$ transitions
- purely left-handed coupling structure favoured by
  - global $b \to s\mu^+\mu^-$ fits
  - total B_c lifetime
  - $B \to D\tau\nu$ differential rate

Towards UV-complete model

Vector leptoquark arising from Pati-Salam gauge group

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

has the right gauge quantum numbers!

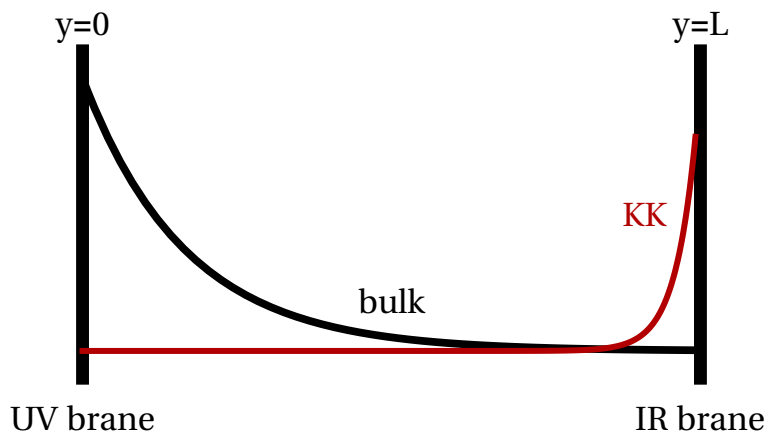
Challenge: flavour non-universal couplings to fermions

Pati-Salam in the Randall-Sundrum background

Idea:
embed Pati-Salam model into the 5D Randall-Sundrum space-time

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

- 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

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

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

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

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

- 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

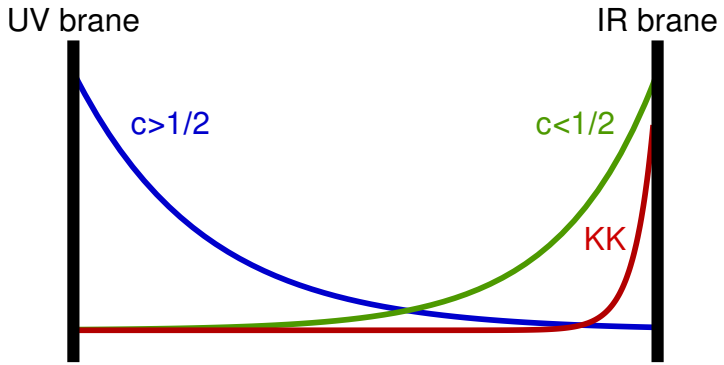
- fermions as 5D bulk fields in complete PS representations

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

  ➢ massless zero modes correspond to SM fermions

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

  ➢ 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
- conposite sector with Pati-Salam global symmetry
- left-handed fermions partially composite – linear mixing of SM fermions with composite resonances: $0 \sim s_1 \ll s_2 \ll s_3 \sim 1/\sqrt{2}$
- right-handed fermions (mostly) elementary

The 4D composite dual

AdS/CFT correspondence: dual 4D composite model

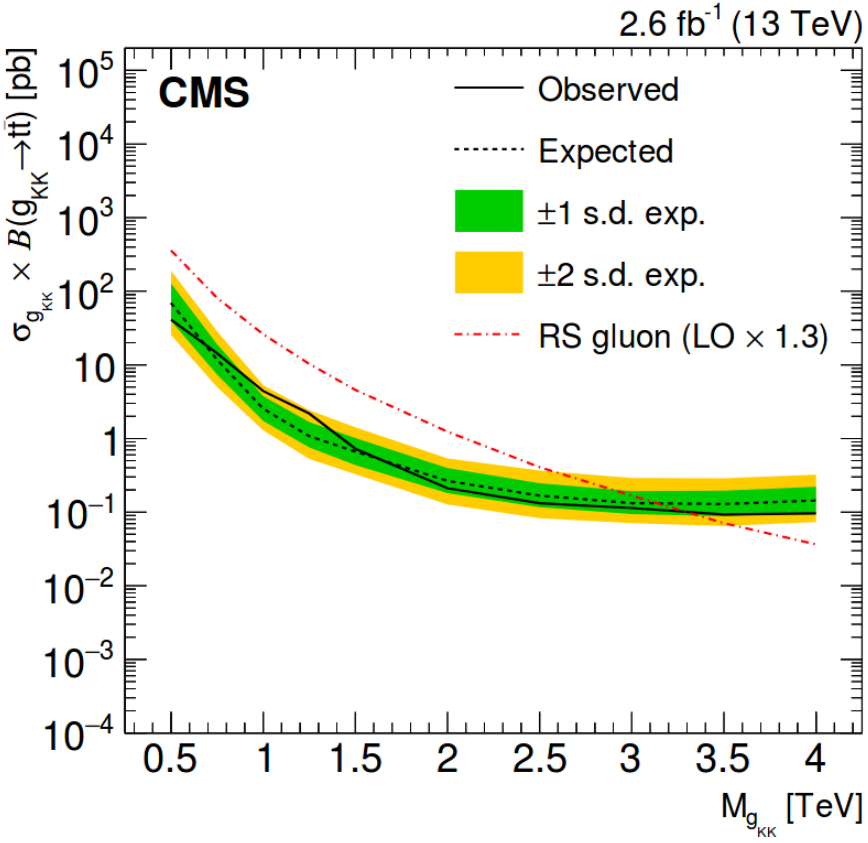
- elementary sector with SM gauge group
- *elementary* Higgs field
- conposite sector with Pati-Salam global symmetry
- left-handed fermions partially composite – linear mixing of SM fermions with composite resonances: $0 \sim s_1 \ll s_2 \ll s_3 \sim 1/\sqrt{2}$
- right-handed fermions (mostly) elementary

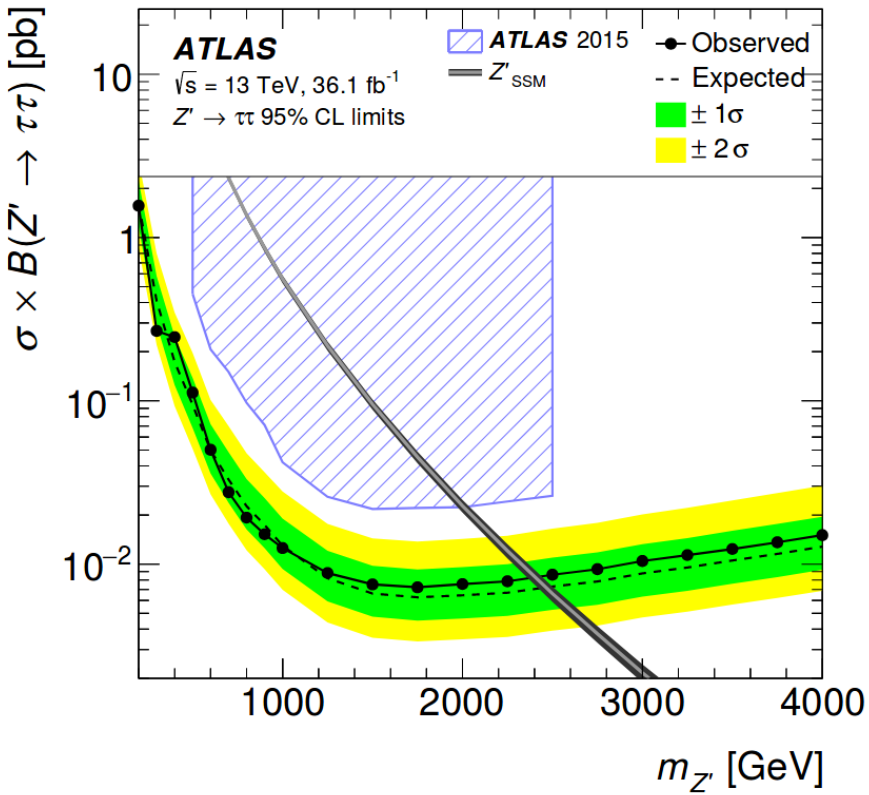
Simplified model: keep only SM fields + lowest-lying KK modes

- 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: $M_{\text{KK}} \geq 3\,\text{TeV}$

Flavour alignment

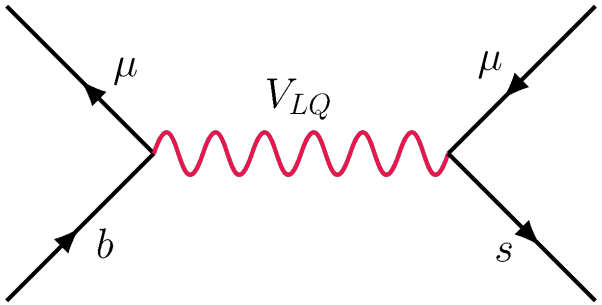
- generically, KK modes of gluons, $B-L$ gauge boson and W_L^3 mediate tree level FCNCs
  - ➢ reintroduces problematic contributions to meson mixings and $b \to s\nu\bar{\nu}$
- avoided by imposing flavour alignment between elementary-composite mixiing (=5D bulk masses) and Y_d
  - ➢ no tree level FCNCs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

$$\Gamma^{LQ,L}_{d_i \ell_j} = \frac{i g_s^*}{\sqrt{2}} \begin{pmatrix} 0 & 0 & 0 \\ 0 & s_2^2 c_\ell & s_2^2 s_\ell \\ 0 & -s_3^2 s_\ell & s_3^2 c_\ell \end{pmatrix}_{ij}$$

$u_i \nu_j$ includes additional CKM rotation

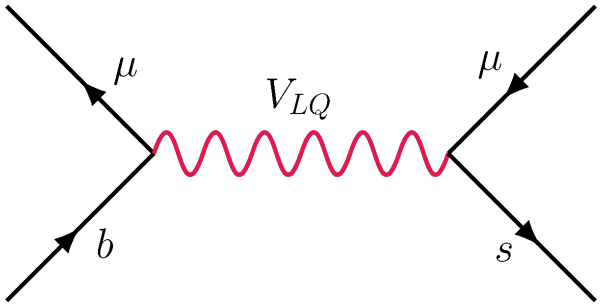
Important tree level effects

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

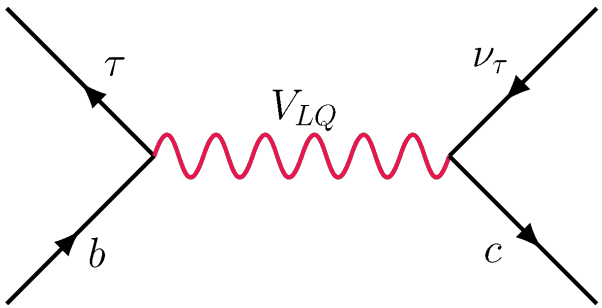


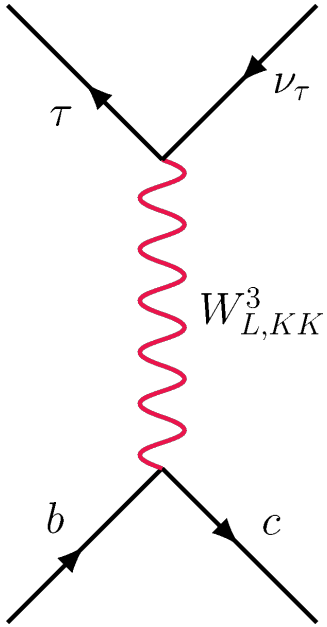
Important tree level effects

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



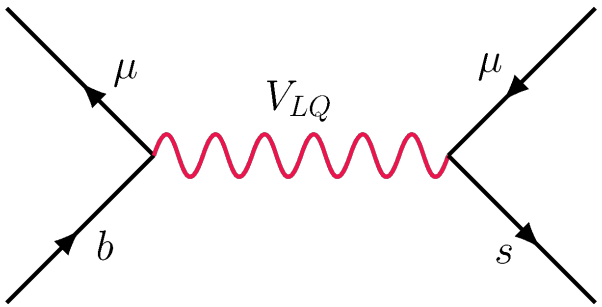
$b \to c\tau\nu$



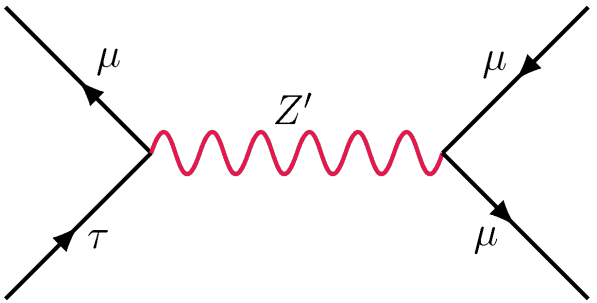


Important tree level effects

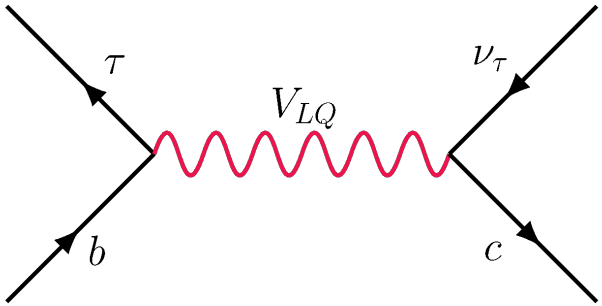
$b \to s\mu^+\mu^-$

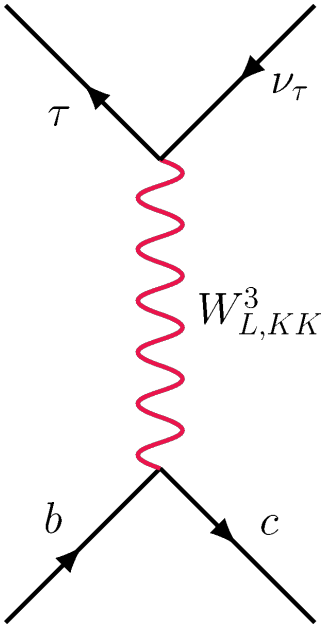


$\tau \to 3\mu$

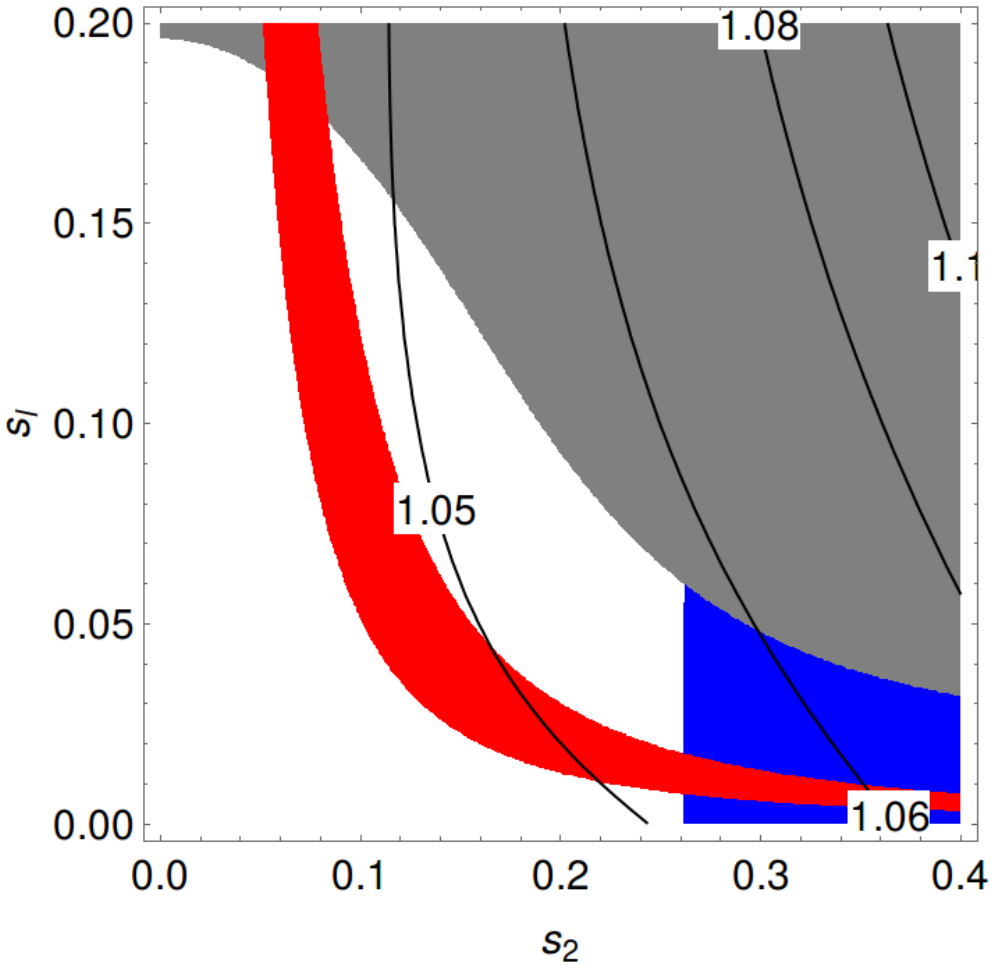


$b \to c\tau\nu$





Can we resolve the B decay anomalies?



s_2: 2nd generation compositeness

s_ℓ: leptonic mixing

B→K$\tau\mu$ excluded

τ→3μ excluded

b→s$\mu\mu$ (2σ)

— R(X)/(R(X))$_{SM}$

PRELIMINARY

Conclusions

- Pati-Salam model in the Randall-Sundrum background provides UV-complete model for $SU(2)_L$ singlet vector leptoquark

- dangerous FCNC contributions from neutral KK gauge bosons evaded by down quark flavour alignment

➢ **full resolution of $b \to s\mu^+\mu^-$ anomaly** and simultaneous **significant enhancement of $R(D)$ and $R(D^*)$**, without relevant fine-tuning in other flavour observables