Flavour physics of a generalized left-right symmetric model

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arXiv: 1111.xxxx
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Left-right symmetric models

Characteristics:

- left-right (LR) symmetric gauge group

$$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

- left and right gauge couplings g_L and g_R
- left and right quark mixing matrices V^L and V^R

Already ...

- known since more than 35 years
- studied extensively by many authors from simplest scenarios with exact LR symmetry to more general frameworks

1. **Lepton Number as the Fourth Color.**
(3155) Jogesh C. Pati (Maryland U.), Abdus Salam (ICTP, Trieste & Imperial Coll., London). IC/74/7. Jan 1974. 35 pp.
Published in **Phys.Rev. D10 (1974) 275-289**

2. **Left-Right Gauge Symmetry and an Isoconjugate Model of CP Violation.**
(1448) Rabindra N. Mohapatra, Jogesh C. Pati (Maryland U.). MDDP-TR-74-085. Mar 1974. 11 pp.
Published in **Phys.Rev. D11 (1975) 566-571**

3. **Exact Left-Right Symmetry and Spontaneous Violation of Parity.**
(1256) G. Senjanovic, Rabindra N. Mohapatra (City Coll., N.Y.). CCNY-HEP-75-5. May 1975. 12 pp.
Published in **Phys.Rev. D12 (1975) 1502**

Is this all?

Is this all?

No!

What is new?

simultaneous analysis of the most interesting
$\Delta F = 2$ observables and $B \to X_{d,s}\gamma$

Further constraints:

- electroweak precision tests
- tree-level decays
- direct experimental bounds

Generality:

- no exact LR symmetry: $g_L \neq g_R$ and $V^L \neq V^R$
- most general parametrization of V^R
  (three new mixing angles and six CP-violating phases)

Attraction:

- masses for heavy gauge bosons around $2 - 3$ TeV able to be measured at LHC

Questions

- Can this class of models be consistent with all existing data for RH scales in reach of LHC?
- What is the role played by the heavy Higgses?
- Can the V_{ub}- problem be solved in this framework?
- Which are the most interesting effects in the flavour sector?
- What can we conclude about the structure of the RH mixing matrix?

Scales and parameters

- two step spontaneous symmetry breaking

$$SU(2)_L \times \underbrace{SU(2)_R \times U(1)_{B-L}}_{\kappa_R\text{: VEV of triplet}} \to \underbrace{SU(2)_L \times U(1)_Y}_{\kappa,\kappa'\text{: VEV of bidoublet}} \to U(1)_Q$$

- characteristic scales
  - $\kappa_R \sim \mathcal{O}(\text{TeV})$ fixes masses of heavy particles
  - $v = \sqrt{\kappa^2 + \kappa'^2} = 174\,\mathrm{GeV}$ can be associated with the SM VEV

- useful parametrization

$$\epsilon = \frac{v}{\kappa_R}, \qquad s = \frac{\kappa'}{v} \qquad \text{and} \qquad c = \frac{\kappa}{v}$$

Heavy particles

Extended Higgs sector:

- only two neutral flavour changing Higgses H_1^0 and H_2^0 and the charged Higgs H^+ with leading order couplings to quarks
- their masses are identical at leading order

$$M_{H_1^0} = M_{H_2^0} = M_{H^+} = M_H$$

Extended gauge sector:

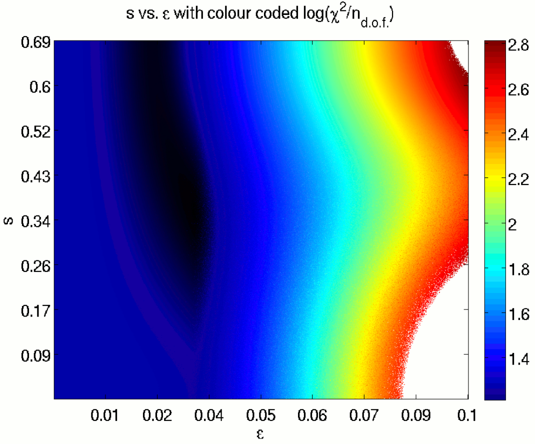
- heavy gauge bosons W_R and Z'
- EWSB introduces small admixture between gauge bosons corresponding to $SU(2)_L$ and $SU(2)_R$

$$\text{mixing} \sim s_R \, sc\epsilon^2$$

Electroweak precision analysis

- parameters ϵ, s, s_R can be constraint using
  - most constraining observables according to the global fit analysis of [Hsieh, Schmitz, Yu, Yuan '2010]
  - additional constraints e.g. M_W and direct bounds on M_{W_R}
- in our analysis we fix:

$$
\begin{aligned}
s &= 0.5 \\
s_R &= 0.8 \\
\epsilon &= 0.03
\end{aligned}
$$



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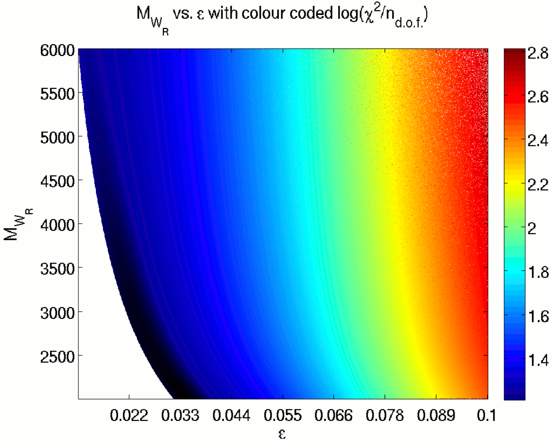
- in our analysis we fix:

$$s c \epsilon^2 \approx 3.9 \cdot 10^{-4}$$
$$M_{W_R} \approx 2.6\,\mathrm{TeV}$$
$$M_H \approx 16\,\mathrm{TeV}$$



Constraints from tree level decays

- vectorial and axial combinations of LH and RH mixing matrices

$$|V_{ij}|_V = \left| V^L_{ij} + cs\epsilon^2 V^R_{ij} \right| \qquad |V_{ij}|_A = \left| V^L_{ij} - cs\epsilon^2 V^R_{ij} \right|$$

- constrained by tree-level charged current transitions

transition	considered decay	$\vert V^L_{ij}\vert$	$\vert V_{ij}\vert_V$	$\vert V_{ij}\vert_A$
$u \to d$	superallowed $0^+ \to 0^+$	-	0.97425(22)	-
	$\pi^+ \to \mu^+\nu$	-	-	0.981(13)
$u \to s$	$K \to \pi\ell\nu$	-	0.2257(12)	-
	$K \to \mu\nu$	-	-	0.2268(32)
$c \to d$	$D \to K\ell\nu$ and $D \to \pi\ell\nu$	-	0.229(25)	-
	νN charm production	-	-	0.230(11)
$c \to s$	semileptonic D decays	-	0.98(10)	-
	$D_s \to \tau^+\nu$	-	-	0.978(31)
$b \to u$	$B \to X_u\ell\nu$	$4.27(38) \cdot 10^{-3}$	-	-
	$B \to \pi\ell\nu$	-	$3.38(36) \cdot 10^{-3}$	-
	$B \to \tau\nu$	-	-	$4.70(56) \cdot 10^{-3}$
$b \to c$	$B \to X_c\ell\nu_\ell$	$41.54(73) \cdot 10^{-3}$	-	-
	$B \to D\ell\nu$	-	$39.4(17) \cdot 10^{-3}$	-
	$B \to D^*\ell\nu$	-	-	$39.70(92) \cdot 10^{-3}$
$t \to b$	$Br(t \to bW)/Br(t \to qW)$	0.95(5)	-	-

Constraints from tree level decays

- vectorial and axial combinations of LH and RH mixing matrices

$$|V_{ij}|_V = \left|V_{ij}^L + cs_\epsilon^2 V_{ij}^R\right| \qquad |V_{ij}|_A = \left|V_{ij}^L - cs_\epsilon^2 V_{ij}^R\right|$$

- tension between inclusive and exclusive determinations of $|V_{ub}|$

transition	considered decay	$\lvert V_{ij}^L\rvert$	$\lvert V_{ij}\rvert_V$	$\lvert V_{ij}\rvert_A$
$b \to u$	$B \to X_u \ell\nu$	$4.27(38) \cdot 10^{-3}$	-	-
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- V_{ub} problem
  - can in principle be resolved in presence of RH currents [Crivellin '09]
  - confirmed by an effective theory approach with RH currents [Buras, KG, Isidori '10]

Constraints from tree level decays

- vectorial and axial combinations of LH and RH mixing matrices

$$|V_{ij}|_V = \left|V^L_{ij} + cs\epsilon^2 V^R_{ij}\right| \qquad |V_{ij}|_A = \left|V^L_{ij} - cs\epsilon^2 V^R_{ij}\right|$$

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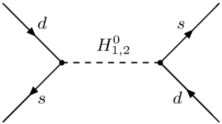
- V_{ub} problem solved for $sc\epsilon^2 |V^R_{ub}| \sim 6 \times 10^{-4}$

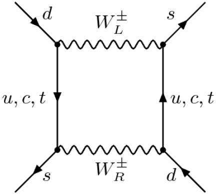
$$sc\epsilon^2 \sim 4 \cdot 10^{-4} \text{ (EWPT)} \qquad \text{and} \qquad |V^R_{ub}| \lesssim \begin{cases} 1 & \text{(unitarity)} \\ 0.2 & \text{(full analysis)} \end{cases}$$

In this concrete model the V_{ub} problem cannot be solved.

$\Delta F = 2$ processes

- main impact from LR operators
- diagrams:





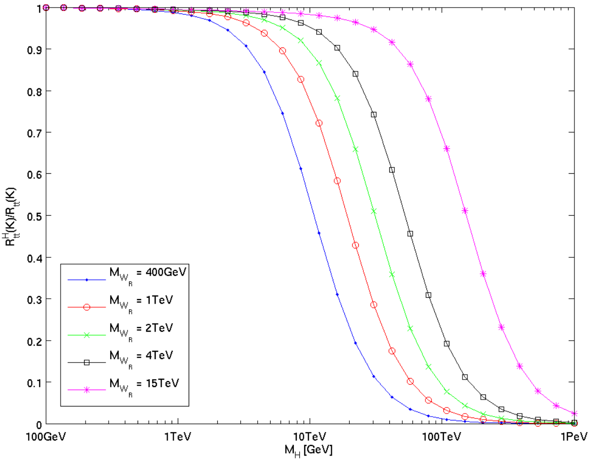
- dominant NP mixing amplitude for meson system $q = K, B_d, B_s$

$$(M_{12})_{\rm LR} \sim \sum_{i,j=u,c,t} \left[\lambda_i^{\rm LR}(q)\lambda_j^{\rm RL}(q)\right]^* R_{ij}(q)$$

$\lambda_i^{\rm LR}(q), \lambda_j^{\rm RL}(q)$ - involve quark mixing matrices V^L and V^R

$R_{ij}(q)$ - involves loop integral and QCD running

Role of the neutral Higgses



- contribution of neutral Higgs to $R_{tt}(K)$
- **Example:**

$$M_{W_R} = 2.6\,\mathrm{TeV}$$
$$M_H = 16\,\mathrm{TeV}$$

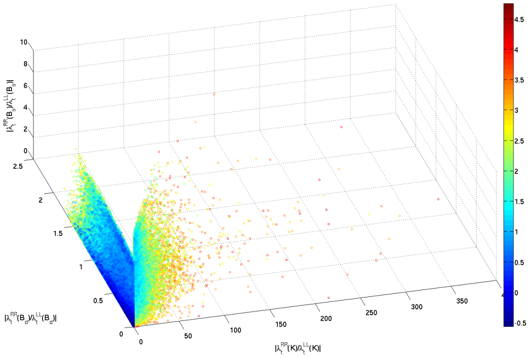
$\Rightarrow$ neutral Higgs $>$ 80% of the LR contribution

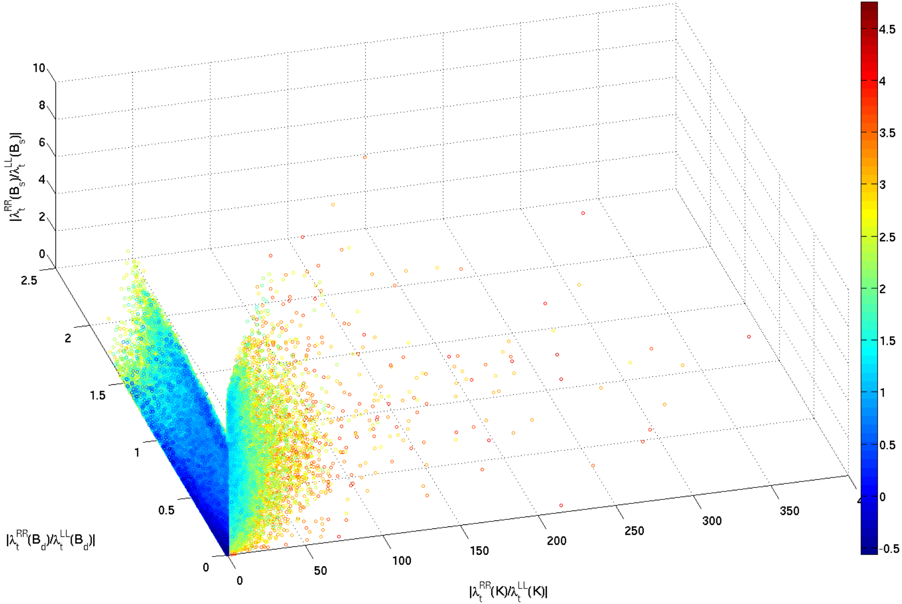
The tree-level contributions of the neutral Higgs are by far dominant and cannot be neglected as often done in literature.

Size of effects in the meson systems

- relevant prefactor of quark flavour matrices:

$$\frac{\lambda_t^{\mathrm{LR}}(q)\lambda_t^{\mathrm{RL}}(q)}{\lambda_t^{\mathrm{LL}}(q)\lambda_t^{\mathrm{LL}}(q)} = \frac{\lambda_t^{\mathrm{LL}}(q)\lambda_t^{\mathrm{RR}}(q)}{\lambda_t^{\mathrm{LL}}(q)\lambda_t^{\mathrm{LL}}(q)} = \frac{\lambda_t^{\mathrm{RR}}(q)}{\lambda_t^{\mathrm{LL}}(q)}$$




$|\lambda_t^{RR}(B_s)/\lambda_t^{LL}(B_s)|$
$|\lambda_t^{RR}(B_d)/\lambda_t^{LL}(B_d)|$
$|\lambda_t^{RR}(K)/\lambda_t^{LL}(K)|$
0
2
4
6
8
10
0
0.5
1
1.5
2
2.5
0
50
100
150
200
250
300
350
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

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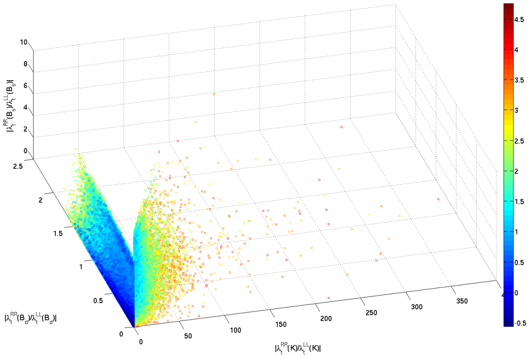


- large effects in the K system
- small / negligible effects in B_s / B_d

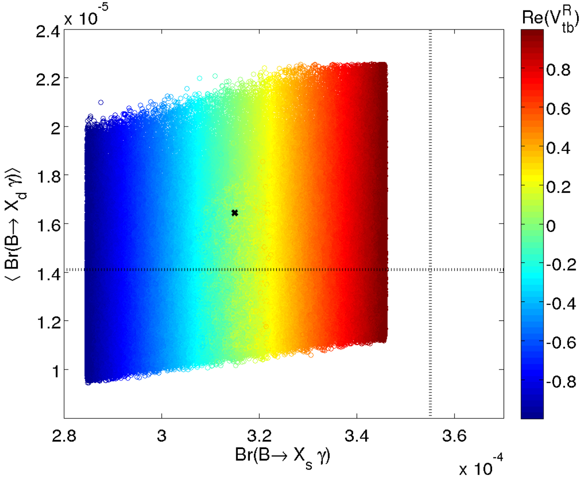
Main messages from $B \to X_s\gamma$

Theory:

- (Charged) Higgs exchanges are similarly important to $\Delta F = 2$ case

Phenomenology:

- enhancement in $\mathrm{Br}(B \to X_s\gamma)$ depending on the V_{tb}^R element and parameter s



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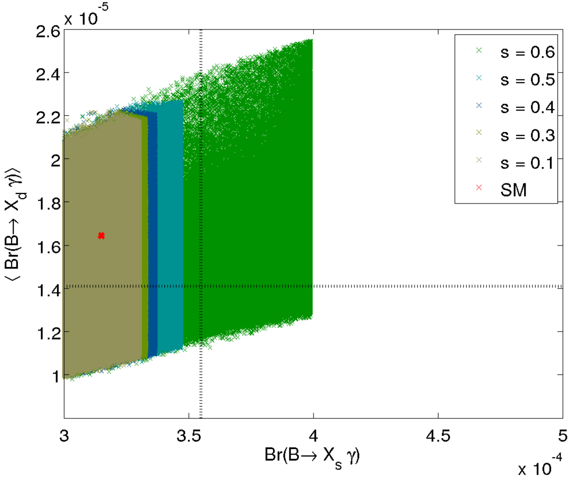
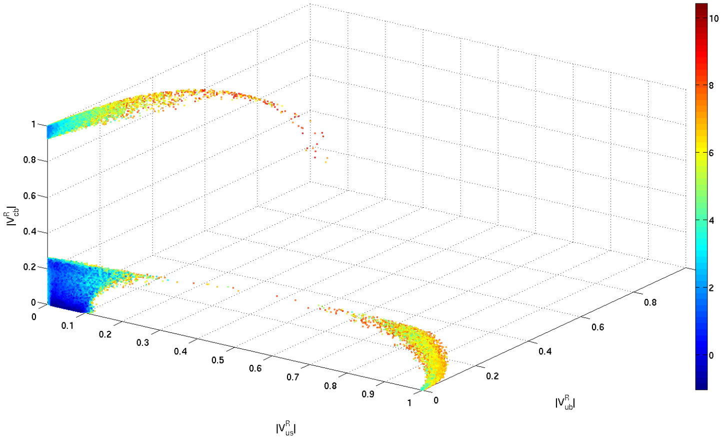
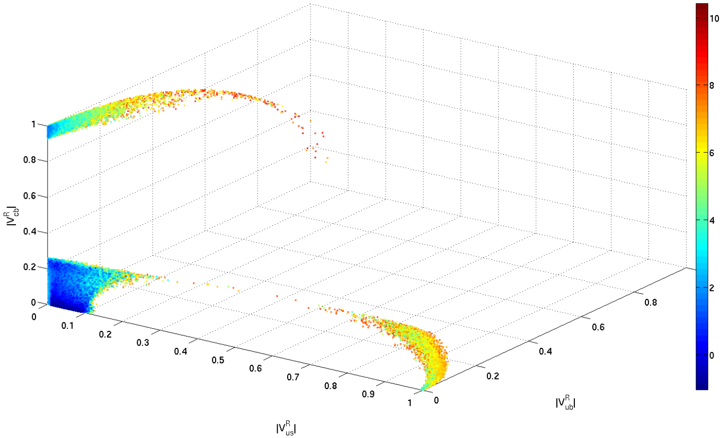


General structure of the RH mixing matrix



- possible to classify two scenarios with low fine-tuning
- find a simplified matrix with fewer parameters, which can solve tensions in SM flavour observables

General structure of the RH mixing matrix



- possible to classify two scenarios with low fine-tuning
- find a simplified matrix with fewer parameters, which can solve tensions in SM flavour observables

Conclusions

- Can this class of models be consistent with all existing data for RH scales in reach of LHC?
  $\rightarrow$ Yes
- What is the role played by the heavy Higgses?
  $\rightarrow$ a dominant role
- Can the V_{ub}- problem be solved in this framework?
  $\rightarrow$ No
- Which are the most interesting effects in the flavour sector?
  $\rightarrow$ big effects in the K sector
  $\rightarrow$ enhancement of $\mathrm{Br}(B \rightarrow X_s\gamma)$
- What can we conclude about the structure of the RH mixing matrix?
  $\rightarrow$ in general complicated, but possibility of identifying two scenarios with low fine-tuning

Definition of fine-tuning

Barbieri-Giudice fine-tuning:

sensitivity of observables to small variation of model parameters

$$\Delta_{\mathrm{BG}}(Obs) = \max_i \left| \frac{par_i}{Obs} \frac{\partial Obs}{\partial par_i} \right|$$

modified Barbieri-Giudice fine-tuning:

$$\Delta_{\mathrm{BG}}^{\mathrm{mod}} = \frac{1}{N_{Obs}} \sum_{j=1}^{N_{Obs}} \Delta_{\mathrm{BG}}(Obs_j)$$

Obs - observable
par - parameter
N_{Obs} - number of observables

Parameter counting

- gauge sector:

$$g_s\,, \quad g_L\,, \quad g_R\,, \quad g'$$

- Higgs sector:

$$m_H\,, \quad v\,, \quad s\,, \quad \kappa_R$$

- flavour sector:

V^L - three angles and one phase

V^R - three angles and six phases

Definition of λ_i factors

Depending on the Meson system the factors λ_i read

$$\begin{aligned} \lambda_i^{AB}(K) &= V_{is}^{A*} V_{id}^{B} \\ \lambda_i^{AB}(B_q) &= V_{ib}^{A*} V_{iq}^{B} \end{aligned}$$

where the indices are given by

$$\begin{aligned} A, B &= L, R \\ q &= d, s \\ i &= u, c, t \end{aligned}$$