# Addressing $R_K$ and neutrino mixing in a class of $U(1)_X$ models

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November 29, 2016

# Experimental anomalies and Global fits interpretation

$b \to s\ell\ell$ anomalies at LHCb :

- $$R_K = \frac{\mathcal{BR}(B^+ \to K^+\mu\mu)}{\mathcal{BR}(B^+ \to K^+ee)} = 0.745^{+0.090}_{-0.074} \pm 0.036 \ \text{for } q^2 \in \ [1,6]\, GeV^2.$$

  SM prediction : $1 \pm 0.001 \Rightarrow$ **Lepton flavour non-universality**

- $P_5'$ for $B \to K^*\mu\mu$

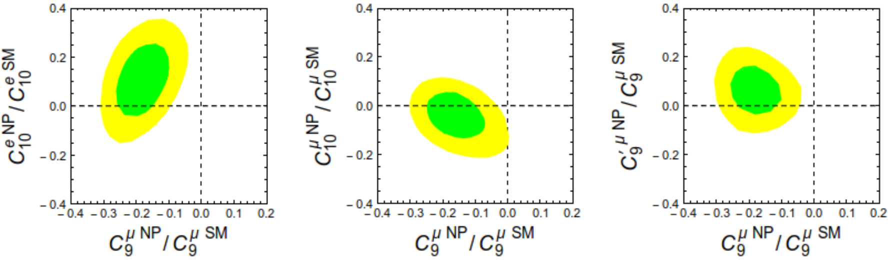
Global fits : Simultaneous explanation if NP in **vector-axial** operators

- $$\begin{aligned} \mathcal{O}_9^\ell &= \bar{b}\gamma_\mu P_L s\, \bar{\ell}\gamma^\mu \ell\,, \quad \mathcal{O}_{10}^\ell = \bar{b}\gamma_\mu P_L s\, \bar{\ell}\gamma^\mu\gamma_5 \ell\,, \\ \mathcal{O}_9'^\ell &= \bar{b}\gamma_\mu P_R s\, \bar{\ell}\gamma^\mu \ell\,, \quad \mathcal{O}_{10}'^\ell = \bar{b}\gamma_\mu P_R s\, \bar{\ell}\gamma^\mu\gamma_5 \ell\,. \end{aligned}$$

# Global fits continued ...

Results taken from T. Hurth, F. Mahmoudi and S. Neshatpour, Nucl. Phys. B **909**, 737 (2016)

2-D global fits in $(C_9^{\mathrm{NP},\mu}, C_9^{\mathrm{NP},e})$, $(C_9^{\mathrm{NP},\mu}, C_{10}^{\mathrm{NP},\mu})$ and $(C_9^{\mathrm{NP},\mu}, C_9^{\prime\mu})$




- $\chi^2$ for $(C_9^{\mathrm{NP},\mu}, C_9^{\mathrm{NP},e})$ better
- $C_9^{\mathrm{NP},e} \neq 0$ allowed within $2\sigma$

# Model building by taking RK anomaly at face value

- Introduce NP in $\mathcal{O}_9^\mu$ and $\mathcal{O}_9^e$ using $Z'$ of a $U(1)_X$ symmetry.
  - $R_K \Rightarrow$ diff $X$-charges for $e$ and $\mu$
  - dominant $Z'$ effects $\Rightarrow$ unequal $X$-charges for $d$-type quarks.

- Explain neutrino-mixings simultaneously with flavour $b \to s$ anomalies.

- $X$-charges of SM fermions:

| Quarks | $Q_1$ | $u_R$ | $d_R$ | $Q_2$ | $c_R$ | $s_R$ | $Q_3$ | $t_R$ | $b_R$ |
|---|---|---|---|---|---|---|---|---|---|
| $U(1)_X$ | $x_{1_L}$ | $x_{1_{uR}}$ | $x_{1_{dR}}$ | $x_{2_L}$ | $x_{2_{cR}}$ | $x_{2_{sR}}$ | $x_{3_L}$ | $x_{3_{tR}}$ | $x_{3_{bR}}$ |
| Leptons | $L_1$ | | $e_R$ | $L_2$ | | $\mu_R$ | $L_3$ | | $\tau_R$ |
| $U(1)_X$ | $y_{1_L}$ | | $y_{1_{eR}}$ | $y_{2_L}$ | | $y_{2_{\mu R}}$ | $y_{3_L}$ | | $y_{3_{\tau R}}$ |

  - $X$-charge of $\Phi_{SM} = a_{\Phi_{SM}}$

# Model building by taking RK anomaly at face value continued ...

- $X$-charges are determined in a **bottom-up** approach (the importance stated in **Camalich's** talk) using constraints from:
    - Anomaly free $U(1)_X$.
    - $K$–$\overline{K}$.
    - $V_{ckm}$.
    - Global fits : Vanishing of $C_9^{\prime,\ell}$ , $C_{10}^{\mathrm{NP},\ell}$.
    - $m_A$.
    - Allowed neutrino textures.

# Constructing the $U(1)_X$ Model

- Introducing 3 $\nu_R$ + assigning vector-like charges, i.e. $x_{1_L} = x_{1_{uR}} = x_{1_{dR}} = x_1$
  - $\Rightarrow$ anomaly free $U(1)_X$,
  - $\Rightarrow$ $X$ charge of $\Phi_{\mathrm{SM}}$ zero,
  - $\Rightarrow$ $\mathcal{C}_{10}^{\mathrm{NP},\ell} = 0$.
- equal $X$-charge of first two generation, i.e. $x_1 = x_2$
  - $\Rightarrow$ relaxed $K$–$\overline{K}$ constraint
  - but $V_{ckm}$ in 1-2 sector : solved by adding $\Phi_{\mathrm{NP}}$ with $X$-charge, $x_1 - x_3$.
- $V_{d_R} \approx 1 \Rightarrow \mathcal{C}_{9,10}^{\prime\mathrm{NP},\ell} = 0$ : achieved with $\Phi_{\mathrm{NP}}$
- Introduce scalar singlet, $S$, charged under $U(1)_X$
  - $\Rightarrow$ masses to $Z'$, $\nu_R$'s
  - $\Rightarrow$ generates $U_{PMNS}$
  - $\Rightarrow$ prevents $m_A \neq 0$.

| Fields | $Q_1$ | $Q_2$ | $Q_3$ | $L_1$ | $L_2$ | $L_3$ | $\Phi_{\mathrm{SM}}$ | $\Phi_{\mathrm{NP}}$ | $S$ |
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# Constructing the $U(1)_X$ Model continued ...

## Selecting neutrino textures in accordance with global fit

- Plot :
  allowed symmetries in lepton sector with atmost two-zeros in $M_R$ (in presence of $S$)
  $+$ Global fit contours in $(C_9^{\mu}, C_9^{e})$
- Select : pass $1\sigma + C_9^{\mathrm{NP},e,\mu} \neq 0$.
- Selected combinations (6):

$$\begin{aligned} \text{Type-A} &= Le - 3L_{\mu} \pm L_{\tau} \ , \\ \text{Type-B} &= Le - L_{\mu} \pm 3L_{\tau} \ , \\ & \quad Le - L_{\mu} \pm L_{\tau} \ . \end{aligned}$$

- Determine $X$-charges of quarks using $U(1)_X$ anomaly condition

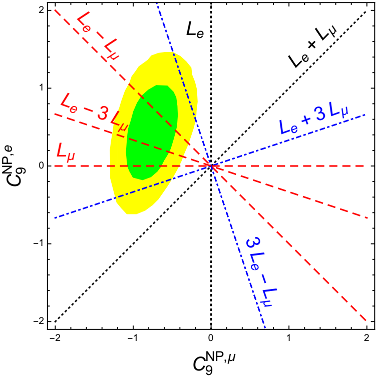


Figure: $\tau$ charge suppressed.

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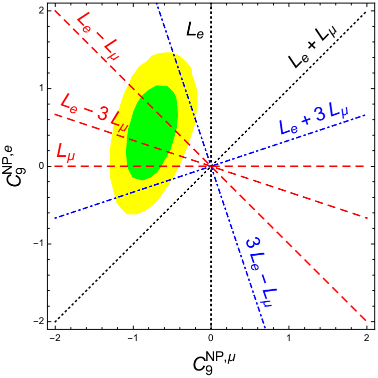


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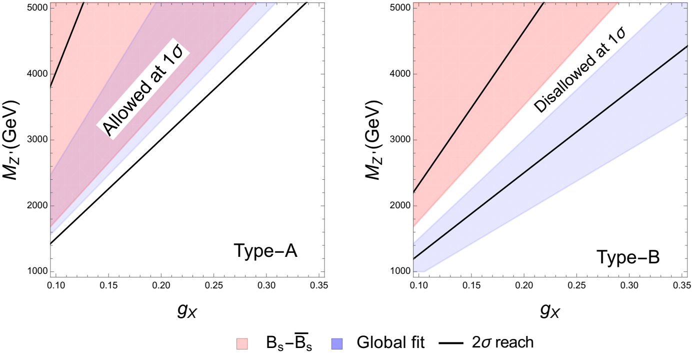
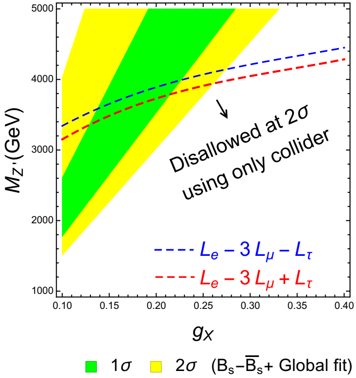
# Combined flavour constraints from neutral meson mixings and global fits




Type-B : no 1 $\sigma$ overlap between $(B_s$–$\overline{B_s})$ and global fit : disregarded
Type-A : Accepted

# Subjecting Type-A symmetries to direct production $Z'$ bounds from colliders

Collider bounds from : $\sigma(pp \to Z' \to \mu\mu)$




Bounds from flavour($B_s$–$\overline{B_s}$), global fit and collider : Substantial overlap

# $R_K$ predictions for Type-A symmetries

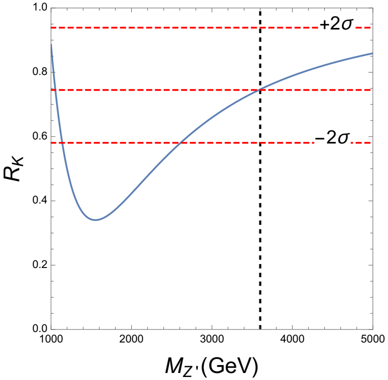



Figure: $g_X = 0.2$

Detection of $Z'$ in $\mu\mu$ channel :

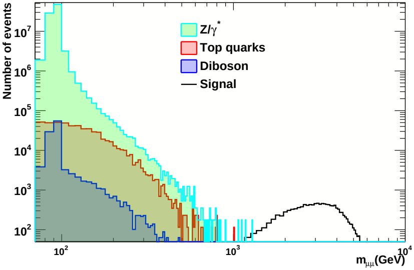



Figure: Schematic for signal access over background for di-muon events

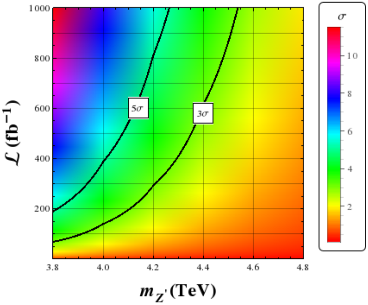



Figure: Significance for detecting $Z'$ with $g_X = 0.2$

# Summarizing

- Two symmetry combinations : $L_e - 3L_\mu \pm L_\tau$ pass all the constraints.
- Additional particles introduced : $Z'$, $\Phi_{\rm NP}$, $S$ and 3 $\nu_R$'s.
- Possible to probe $L_e - 3L_\mu + L_\tau$ at $3\sigma$ with $\sim 60$ fb$^{-1}$ luminosity: $M_{Z'} = 3800$ GeV and $g_X = 0.2$.