Wino contribution to $R_{K^{(*)}}$ anomalies with R-parity violation

Kevin Earl, Thomas Grégoire

arXiv: 1805.xxxxx

Carleton University

May 7, 2018

Pheno 2018

Outline

1. Motivation
2. Calculations
3. Most important constraints
4. Results

$R_{K^{(*)}}$ anomalies

- consider ratio of branching ratios $R_{K^{(*)}}$

$$R_{K^{(*)}} = \frac{\mathrm{Br}(B \to K^{(*)}\mu\mu)}{\mathrm{Br}(B \to K^{(*)}ee)}$$

- Standard Model predictions

$$R^{SM}_{K[1,6]} = 1.00 \pm 0.01 \quad \text{and} \quad R^{SM}_{K^*[1.1,6]} = 1.00 \pm 0.01$$

- current experimental values

$$R^{exp}_{K[1,6]} = 0.745^{+0.097}_{-0.082} \quad \text{and} \quad R^{exp}_{K^*[1.1,6]} = 0.685^{+0.122}_{-0.083}$$

- each represent $\sim 2.6\sigma$ deviations from the Standard Model
- numbers from Capdevila, Crivellin, Descotes-Genon, Matias, Virto '17

Multiple $b \to s\mu\mu$ anomalies

- other observables related to $b \to s\mu\mu$ exhibiting anomalous behaviour
- includes things like angular variables $P_1, P'_{4,5,6,8}$, ...
- one way to explain anomalies is to generate negative contributions to C^{μ}_{LL} defined by

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts} \frac{\alpha}{4\pi} C^{\mu}_{LL} (\bar{s}\gamma_\alpha P_L b)(\bar{\mu}\gamma^\alpha P_L \mu)$$

- Capdevila, Crivellin, Descotes-Genon, Matias, Virto '17 give preferred 2σ region

$$-1.76 < C^{\mu}_{LL} < -0.74$$

- see also Altmannshofer, Niehoff, Stangl, Straub '17

R-parity violating superpotential

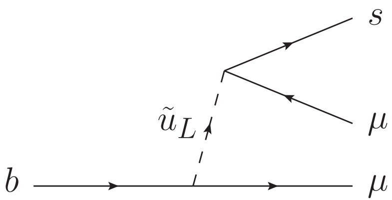
$$W_{\not R_p} = \frac{1}{2}\lambda LLE^c + \lambda' LQD^c + \frac{1}{2}\lambda'' U^c D^c D^c + \epsilon H_u L$$

- focus on λ' interactions
- work in the super-CKM basis

$$\begin{aligned}\mathcal{L} \supset &- \lambda'_{ijk}(\tilde{\nu}_i d_{Lj}\bar{d}_{Lk} + \tilde{d}_{Lj}\nu_i\bar{d}_{Lk} + \tilde{d}^*_{Rk}\nu_i d_{Lj}) \\ &+ \tilde{\lambda}'_{ijk}(\tilde{e}_{Li}u_{Lj}\bar{d}_{Lk} + \tilde{u}_{Lj}e_{Li}\bar{d}_{Lk} + \tilde{d}^*_{Rk}e_{Li}u_{Lj}) + \text{h.c.}\end{aligned}$$

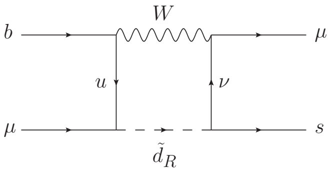
- with $\tilde{\lambda}'_{ijk} = \lambda'_{ilk}V^*_{jl}$

$b \to s\mu\mu$ at tree level

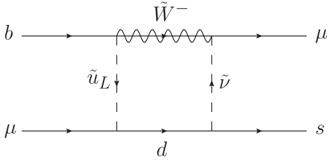


- $\mathcal{L}_{\text{eff}} = -\frac{\tilde{\lambda}'_{2j2}\tilde{\lambda}'^{*}_{2j3}}{2m^2_{\tilde{u}_{Lj}}}(\bar{s}\gamma^\alpha P_R b)(\bar{\mu}\gamma_\alpha P_L \mu)$
- notice right-handed quark current
- need to forbid $\to$ consider only single value for k
- same approach taken in Das, Hati, Kumar, Mahajan '17

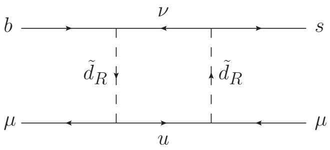
$b \to s\mu\mu$ at loop level: box diagrams



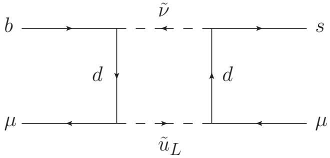
(a)



(b)



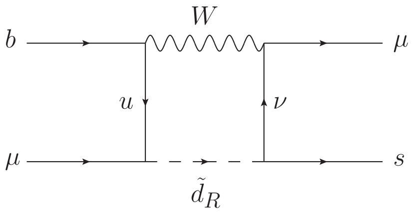
(c)



(d)

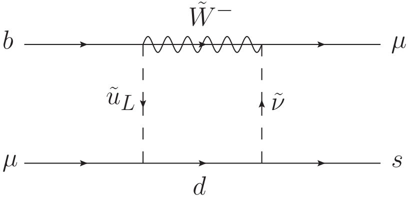
- diagrams (a) and (c) studied in Bauer, Neubert '15
- diagrams (a), (c), and (d) studied in Das, Hati, Kumar, Mahajan '17

W loop diagrams



- $C_{LL}^{\mu(W)} = \frac{|\lambda'_{23k}|^2}{8\pi\alpha}\left(\frac{m_t^2}{m_{\tilde{d}_{Rk}}^2}\right)$

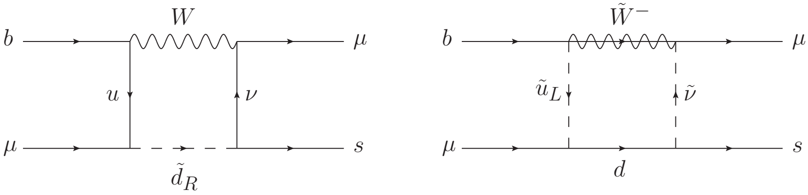
Wino loop diagrams



$$C_{LL}^{\mu(\tilde{W})} = \frac{\sqrt{2} g^2 \lambda'_{23k} \lambda'^*_{22k}}{64\pi G_F \alpha V_{tb} V_{ts}^* m_{\tilde{W}}^2} \left(\frac{1}{x_{\tilde{\nu}_\mu} - 1} + \frac{1}{x_{\tilde{u}_L} - 1} + \frac{(x_{\tilde{\nu}_\mu} - 2x_{\tilde{\nu}_\mu}^2 + x_{\tilde{u}_L}) \log(x_{\tilde{\nu}_\mu})}{(x_{\tilde{\nu}_\mu} - 1)^2 (x_{\tilde{\nu}_\mu} - x_{\tilde{u}_L})} + \frac{(x_{\tilde{u}_L} - 2x_{\tilde{u}_L}^2 + x_{\tilde{\nu}_\mu}) \log(x_{\tilde{u}_L})}{(x_{\tilde{u}_L} - 1)^2 (x_{\tilde{u}_L} - x_{\tilde{\nu}_\mu})} \right)$$

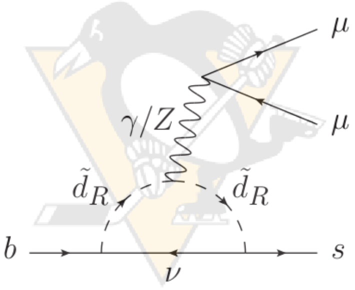
- where $x_{\tilde{\nu}_\mu} = m_{\tilde{\nu}_\mu}^2 / m_{\tilde{W}}^2$, $x_{\tilde{u}_L} = m_{\tilde{u}_L}^2 / m_{\tilde{W}}^2$

Four λ' loop diagrams



$$C_{LL}^{\mu(4\lambda')} = -\frac{\sqrt{2}\lambda'_{i3k}\lambda'^{*}_{i2k}\lambda'_{2jk}\lambda'^{*}_{2jk}}{64\pi G_F \alpha V_{tb} V_{ts}^{*}} \left(\frac{1}{m^2_{\tilde{d}_{Rk}}} + \frac{\log(m^2_{\tilde{\nu}_i}/m^2_{\tilde{u}_L})}{m^2_{\tilde{\nu}_i} - m^2_{\tilde{u}_L}} \right)$$

$b \to s\mu\mu$ at loop level: penguin diagrams



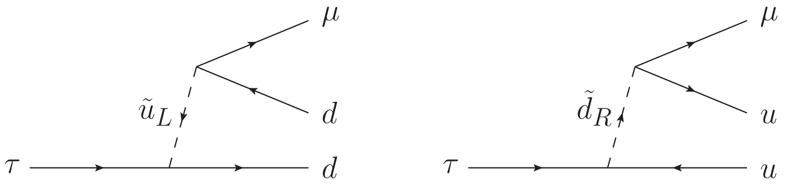
$$C_{LL}^{\mu(\gamma)} = C_{LR}^{\mu(\gamma)} = -\frac{\sqrt{2}\lambda'_{i33}\lambda'^*_{i23}}{12 G_F V_{tb} V_{ts}^*}\left(-\frac{1}{3}\left(\frac{4}{3} + \log\left(\frac{m_b^2}{m_{\tilde{\nu}_i}^2}\right)\right)\frac{1}{m_{\tilde{\nu}_i}^2} + \frac{1}{18 m_{\tilde{b}_R}^2}\right)$$

- give equal contributions to $C_{LL}^{e(\gamma)}$ and $C_{LR}^{e(\gamma)}$ so should not affect $R_{K^{(*)}}$
- but should still affect various angular variables used to make fits
- small in our setup

Setup

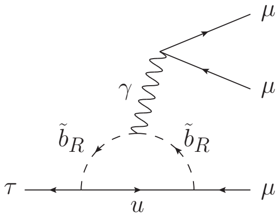
- wino and left-handed up squarks with masses $\sim \mathcal{O}(1\ \text{TeV})$
- to enhance wino loop contribution: $\lambda'_{22k}\lambda'_{23k}$ positive and large
- $B_s - \bar{B}_s$ mixing then requires right-handed down squarks and sneutrinos with masses $\sim \mathcal{O}(10\ \text{TeV})$
- to make some four λ' loop diagrams negative: $\lambda'_{32k}\lambda'_{33k}$ negative
- $\tau \to \mu$ meson then requires us to take $k = 3$
- only right-handed down squark now relevant is the sbottom

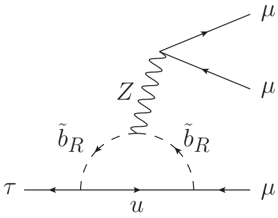
$\tau \to \mu$ meson

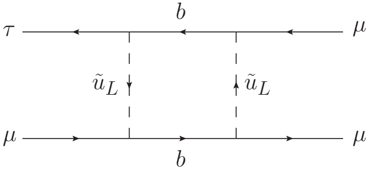


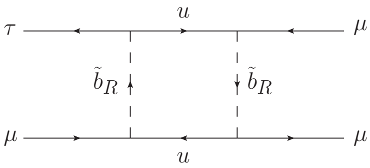
- $\tau \to \mu\rho^0$: $\left|\tilde{\lambda}'_{3j1}\tilde{\lambda}'^*_{2j1}\left(\frac{1\text{TeV}}{m_{\tilde{u}_{Lj}}}\right)^2 - \tilde{\lambda}'_{31k}\tilde{\lambda}'^*_{21k}\left(\frac{1\text{TeV}}{m_{\tilde{d}_{Rk}}}\right)^2\right| < 0.019$
- $\tau \to \mu\phi$: $\left|\tilde{\lambda}'_{3j2}\tilde{\lambda}'^*_{2j2}\left(\frac{1\text{TeV}}{m_{\tilde{u}_{Lj}}}\right)^2\right| < 0.036$
- these two bounds rule out $k = 1$ or 2

$\tau \to \mu\mu\mu$



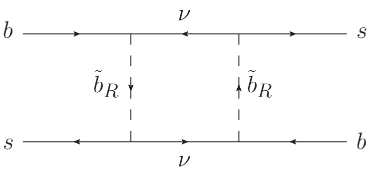


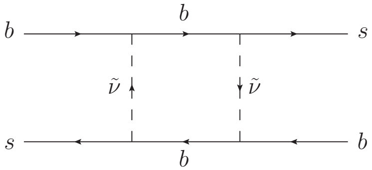




- Current experimental upper limits $\text{Br}(\tau \to \mu\mu\mu) < 2.1 \times 10^{-8}$ (PDG)

$B_s - \bar{B}_s$ mixing



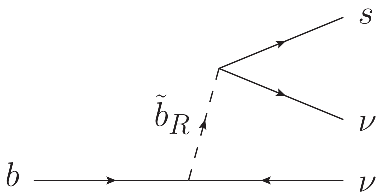


- we follow the UT*fit* collaboration and define

$$C_{B_s} e^{2i\phi_{B_s}} = \frac{\langle B_s^0 | H_{\text{eff}}^{\text{full}} | \bar{B}_s^0 \rangle}{\langle B_s^0 | H_{\text{eff}}^{\text{SM}} | \bar{B}_s^0 \rangle}$$

with 2σ bounds $0.899 < C_{B_s} < 1.252$ and $-1.849^\circ < \phi_{B_s} < 1.959^\circ$

$B \to K^{(*)}\nu\bar{\nu}$

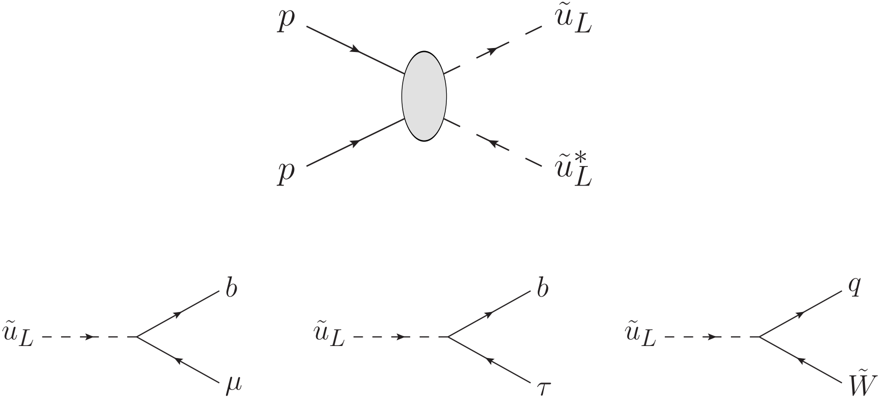


- define

$$R_{B\to K^{(*)}\nu\bar{\nu}} = \frac{\Gamma^{\mathrm{SM+NP}}(B \to K^{(*)}\nu\bar{\nu})}{\Gamma^{\mathrm{SM}}(B \to K^{(*)}\nu\bar{\nu})}$$

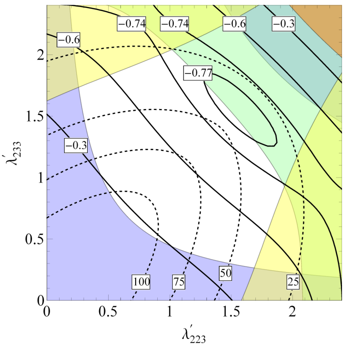
- latest Belle search 1702.03224 provides upper limit $R_{B\to K^*\nu\bar{\nu}} < 2.7$

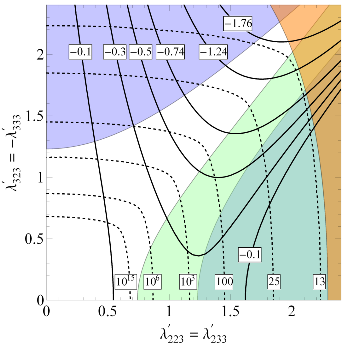
LHC collider constraints



- apply constraints from ATLAS search 1710.05544
- search looks for $\tilde{t}$ pair production with $\tilde{t} \to \ell b$ ($\ell = e$ or μ)

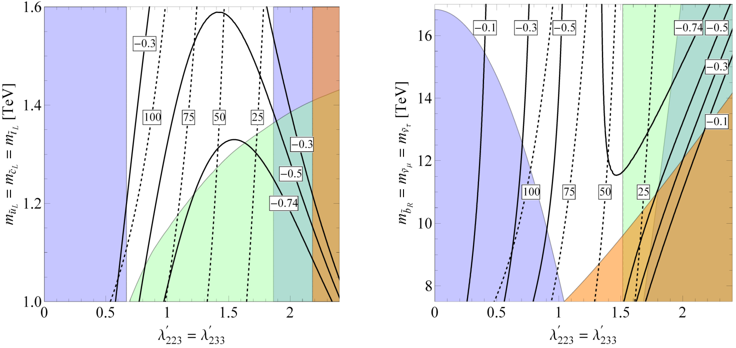
Plots 1 and 2





- left figure: $\lambda'_{323} = -\lambda'_{333} = 1.4$, $m_{\tilde{W}} = 300$ GeV, $m_{\tilde{u}_L} = m_{\tilde{c}_L} = m_{\tilde{t}_L} = 1.3$ TeV, $m_{\tilde{b}_R} = m_{\tilde{\nu}_\mu} = m_{\tilde{\nu}_\tau} = 13$ TeV
- right figure: masses the same as left figure

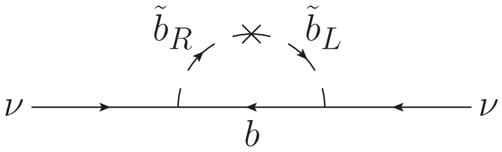
Plots 3 and 4



- parameters not being varied same as in plots 1 and 2

Neutrino masses

- λ' couplings generate neutrino masses



$$M^{\nu}_{ij} = \frac{3}{16\pi^2}\lambda'_{i33}\lambda'_{jl3} m_b (\tilde{m}^{d\,2}_{LR})_{l3} \frac{\log(m^2_{\tilde{b}_R}/m^2_{\tilde{d}_{Ll}})}{m^2_{\tilde{b}_R} - m^2_{\tilde{d}_{Ll}}} + (i \leftrightarrow j)$$

- typical RPVMSSM values $\rightarrow M^{\nu}_{22} \sim 10$ keV, too large
- impose $U(1)_R$ lepton number $\rightarrow \tilde{m}^{d\,2}_{LR}$ forbidden by R-symmetry
- R-symmetry broken by anomaly mediation $\rightarrow M^{\nu}_{22} \sim 1\text{eV}\left(\frac{m_{3/2}}{1\text{GeV}}\right)$