Constraints from measurements of LFU observables

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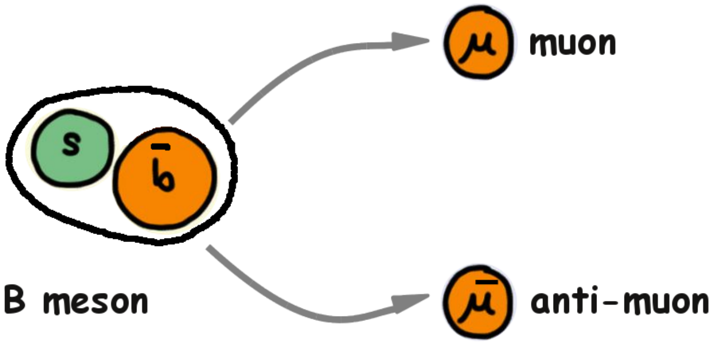
UC SANTA CRUZ

New directions for SUSY searches with LHC Run 3 data
November 15 - 16, 2021

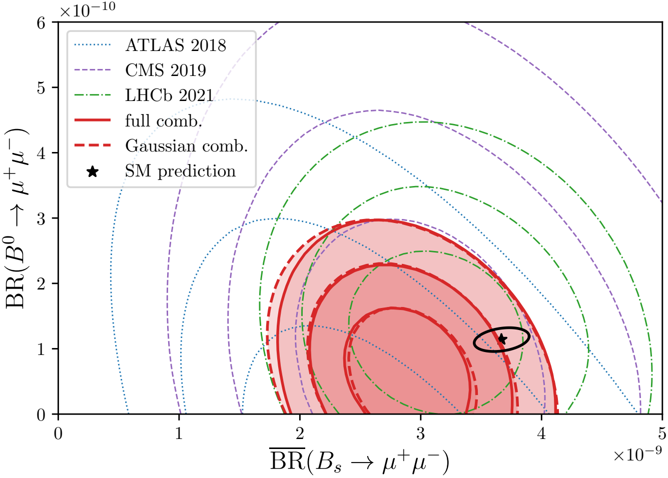
Overview of the Flavor Anomalies

The $B_s \to \mu^+\mu^-$ Decay

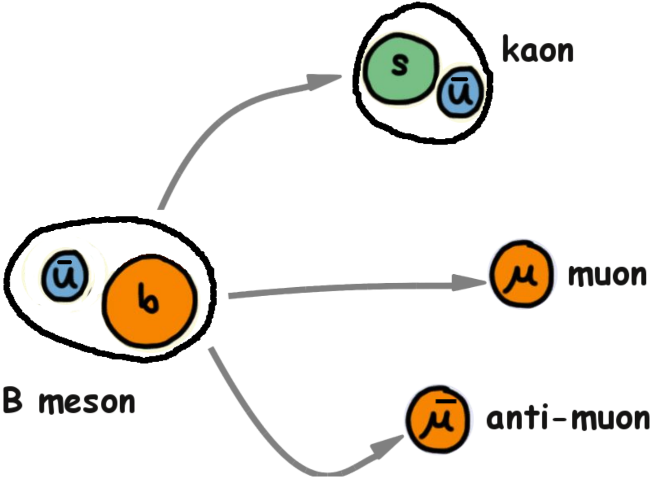


The $B_s \to \mu^+\mu^-$ Branching Ratio

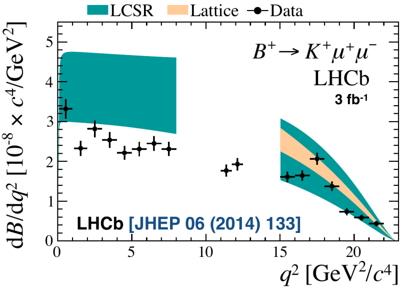
WA, Stangl 2103.13370; combination of LHCb 2108.09284, CMS 1910.12127, ATLAS 1812.03017

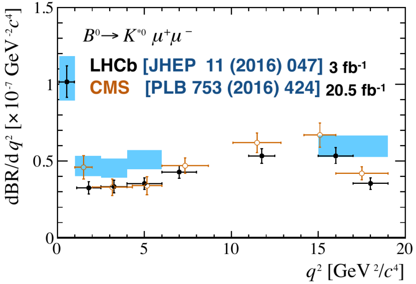


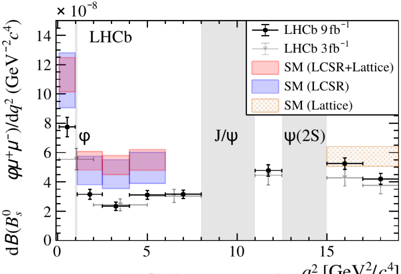
$\sim 2\sigma$ tension between SM and experiment


kaon
s
ū
muon
μ
B meson
ū
b
anti-muon
μ̄

Semileptonic Branching Ratios



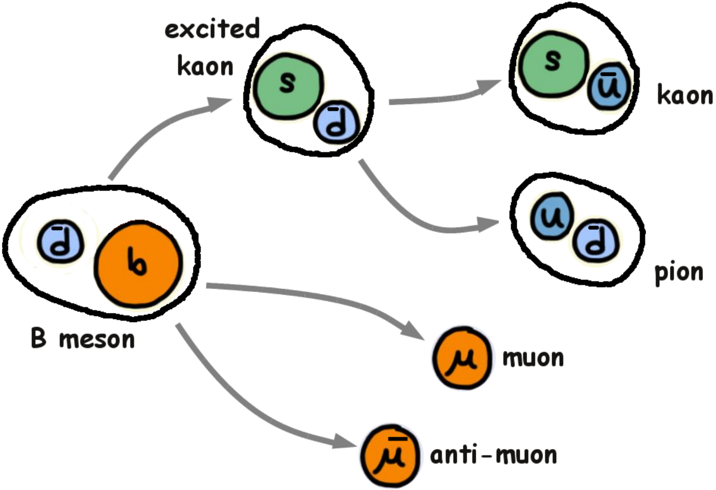




LHCb [2105.14007]

Experimental results for
$\text{BR}(B \to K\mu\mu)$
$\text{BR}(B \to K^*\mu\mu)$
$\text{BR}(B_s \to \phi\mu\mu)$
are consistently low
across many q^2 bins
$(\sim 2\sigma - 3\sigma)$

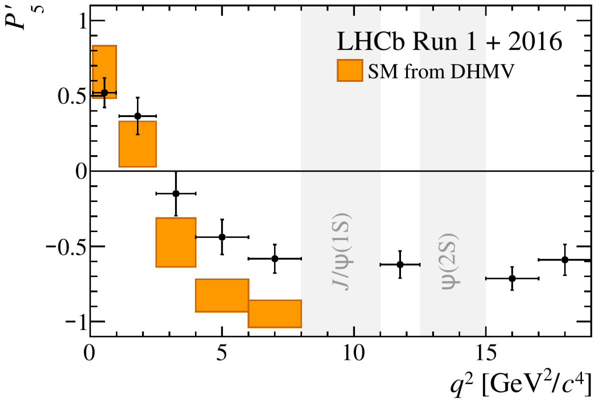
The $B \to K^*(\to K\pi)\mu^+\mu^-$ Decay



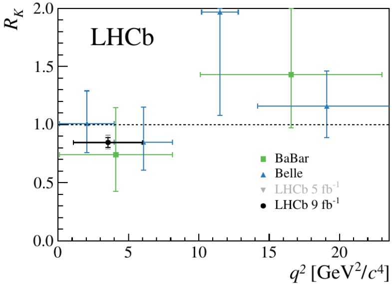
The P_5' Anomaly

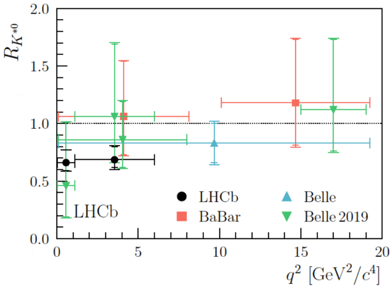
$P_5' \sim$ a moment of the $B \to K^* \mu^+ \mu^-$ angular distribution

LHCb 2003.04831



$\sim 2\sigma - 3\sigma$ anomaly persists in the latest update of $B^0 \to K^{*0} \mu^+ \mu^-$.
(Anomaly also seen in $B^\pm \to K^{*\pm} \mu^+ \mu^-$ LHCb 2012.13241)





$$R_{K^{(*)}} = \frac{BR(B \to K^{(*)}\mu\mu)}{BR(B \to K^{(*)}ee)} \overset{\text{SM}}{\simeq} 1$$

$$R_{K^+}^{[1,6]} = 0.846^{+0.042}_{-0.039}{}^{+0.013}_{-0.012}\ (3.1\sigma)$$

$$R_{K^{*0}}^{[0.045,1.1]} = 0.66^{+0.11}_{-0.07} \pm 0.03\ (\sim 2.5\sigma)$$

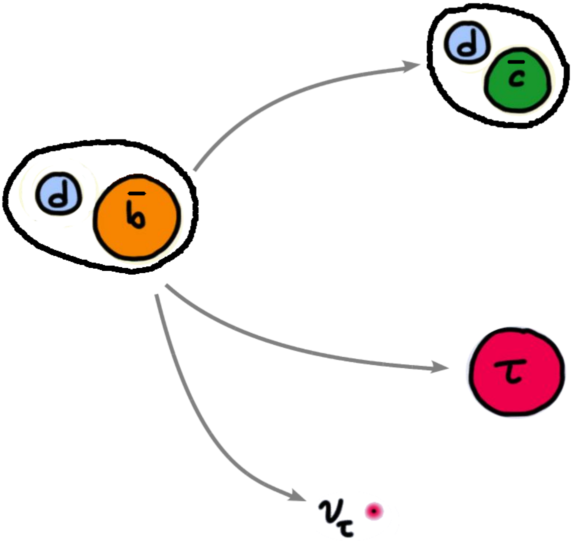
$$R_{K^{*0}}^{[1.1,6]} = 0.69^{+0.11}_{-0.07} \pm 0.05\ (\sim 2.5\sigma)$$

$$R_{K_S}^{[1.1,6]} = 0.66^{+0.20}_{-0.14}{}^{+0.02}_{-0.04}\ (\sim 1.5\sigma)$$

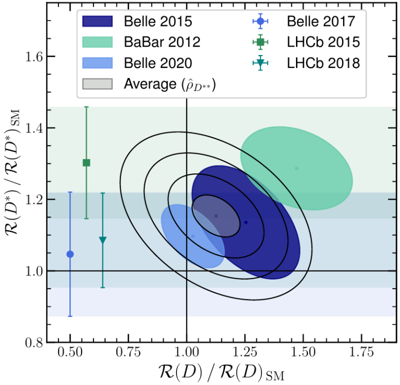
$$R_{K^{*+}}^{[0.045,6]} = 0.70^{+0.18}_{-0.13}{}^{+0.03}_{-0.04}\ (\sim 1.5\sigma)$$

$$R_{pK}^{[0.1,6]} = 0.86^{+0.14}_{-0.11} \pm 0.05\ (\sim 1\sigma)$$

LHCb 2103.11769


d
b̄
d
c̄
τ
ν_τ

Bernlochner, Franco Sevilla, Robinson, 2101.08326



$$R_D = \frac{BR(B \to D\tau\nu)}{BR(B \to D\ell\nu)}$$

$$R_{D^*} = \frac{BR(B \to D^*\tau\nu)}{BR(B \to D^*\ell\nu)}$$

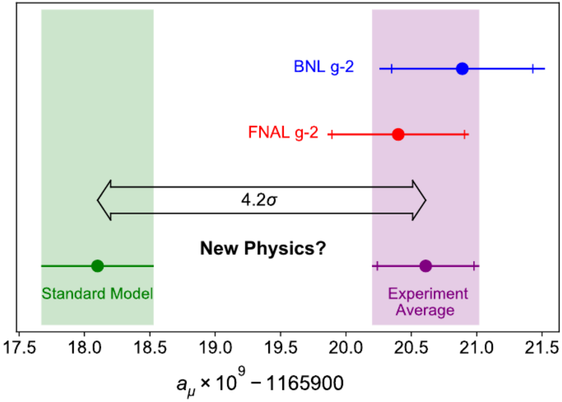
$\ell = \mu, e$ (BaBar/Belle)
$\ell = \mu$ (LHCb)

$$R_D^{\rm exp}/R_D^{\rm SM} = 1.13 \pm 0.10\ , \quad R_{D^*}^{\rm exp}/R_{D^*}^{\rm SM} = 1.15 \pm 0.06$$

combined discrepancy with the SM: 3.6σ

(the heavy flavor averaging group quotes 3.1σ)

Anomalous Magnetic Moment of the Muon

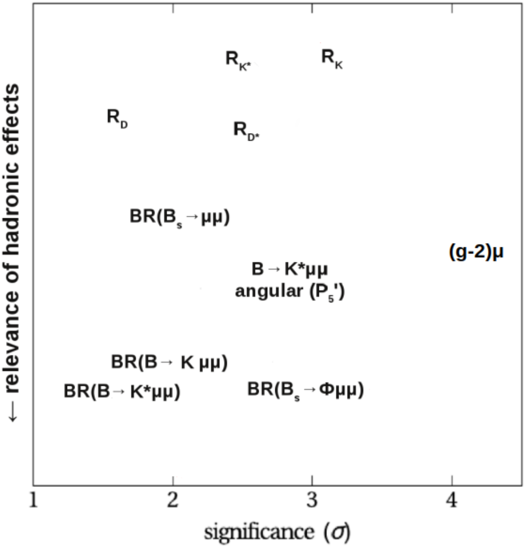


4.2 σ discrepancy between the experimental average (Fermilab g-2, 2104.03281) and the SM consensus (Aoyama et al. 2006.04822)

(see, however, the lattice results from BMW 2002.12347)

$$\Delta a_\mu = (251 \pm 59) \times 10^{-11}$$

(Selection of) Flavor Anomalies in 2021



(inspired by Zoltan Ligeti)

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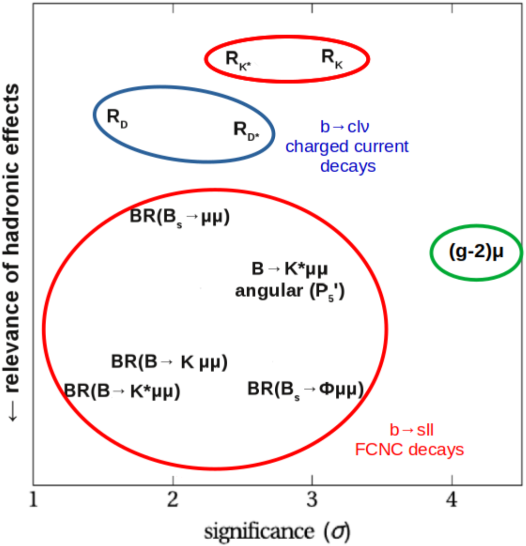

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What Could It Be?

	$B_s \to \mu\mu$ rate	semileptonic rates	angular observables	LFU ratios	$(g-2)_\mu$

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underestimated hadronic effects?	✗	✓	✓	✗	✓
New Physics?	✓	✓	✓	✓	✓

Interlude:
Model Independent
Implications

Model Independent Analysis of $(g-2)_\mu$

The leading effective operator that modifies the anomalous magnetic moment of the muon and that respects $SU(2)_L \times U(1)_Y$

$$\mathcal{L}_{\text{eff}} = \frac{C}{\Lambda_{\text{NP}}^2} H(\bar{\mu}\sigma_{\alpha\beta}\mu)F^{\alpha\beta} \quad \Rightarrow \quad \Delta a_\mu \simeq \frac{4m_\mu v}{e\sqrt{2}\Lambda_{\text{NP}}^2}$$

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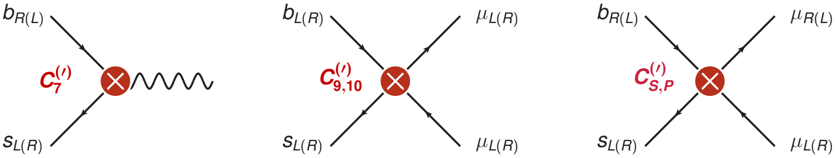
strong coupling	$\frac{1}{\Lambda_{\text{NP}}^2} H(\bar{\mu}\sigma_{\alpha\beta}\mu)F^{\alpha\beta}$	$\Lambda_{\text{NP}} \simeq 290$ TeV
weak coupling	$\frac{e}{16\pi^2}\frac{1}{\Lambda_{\text{NP}}^2} H(\bar{\mu}\sigma_{\alpha\beta}\mu)F^{\alpha\beta}$	$\Lambda_{\text{NP}} \simeq 14$ TeV
weak coupling + MFV	$\frac{e y_\mu}{16\pi^2}\frac{1}{\Lambda_{\text{NP}}^2} H(\bar{\mu}\sigma_{\alpha\beta}\mu)F^{\alpha\beta}$	$\Lambda_{\text{NP}} \simeq 280$ GeV

(MFV = Minimal Flavor Violation)

Model Independent Analysis of R_K and R_{K^*}

$$\mathcal{H}_{\text{eff}}^{b\to s} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i \left(C_i \mathcal{O}_i + C_i' \mathcal{O}_i' \right)$$

magnetic dipole operators | semileptonic operators | scalar operators



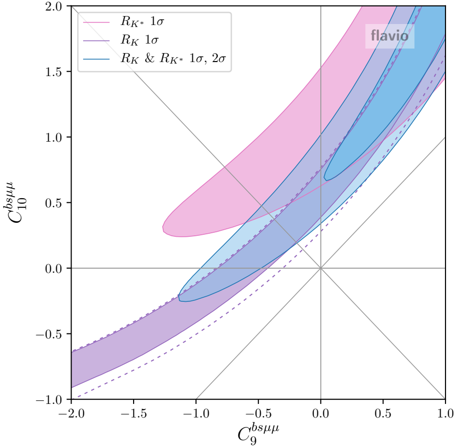
$$C_7^{(\prime)} (\bar{s}\sigma_{\mu\nu} P_{R(L)} b) F^{\mu\nu} \quad , \quad C_9^{(\prime)} (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \ell) \quad , \quad C_S^{(\prime)} (\bar{s} P_{R(L)} b)(\bar{\ell} P_{L(R)} \ell)$$

$$C_{10}^{(\prime)} (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

neglecting tensor operators and additional scalar operators

(they are dimension 8 in SMEFT: Alonso, Grinstein, Martin Camalich 1407.7044)

Global Rare B Decay Fits



$$C_9^{bs\mu\mu}(\bar{s}\gamma_\alpha P_L b)(\bar{\mu}\gamma^\alpha \mu)$$

$$C_{10}^{bs\mu\mu}(\bar{s}\gamma_\alpha P_L b)(\bar{\mu}\gamma^\alpha \gamma_5 \mu)$$

- LFU ratios prefer non-standard C_{10}, but large degeneracy

WA, Stangl 2103.13370 (other recent fits: Geng et al. 2103.12738; Cornella et al. 2103.16558; Alguero et al. 2104.08921; Hurth et al. 2104.10058; Ciuchini et al. 2110.10126)

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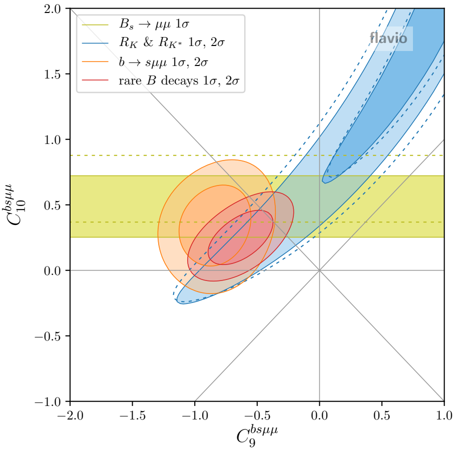

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$$C_9^{bs\mu\mu}(\bar{s}\gamma_\alpha P_L b)(\bar{\mu}\gamma^\alpha \mu)$$

$$C_{10}^{bs\mu\mu}(\bar{s}\gamma_\alpha P_L b)(\bar{\mu}\gamma^\alpha \gamma_5 \mu)$$

- LFU ratios prefer non-standard C_{10}, but large degeneracy
- $B_s \to \mu^+\mu^-$ branching ratio shows slight preference for non-standard C_{10}
- $b \to s\mu\mu$ observables prefer non-standard C_9
- best fit point

$$C_9^{bs\mu\mu} \simeq -0.63$$

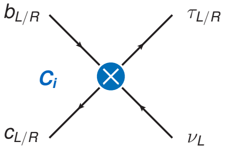
$$C_{10}^{bs\mu\mu} \simeq +0.25$$

The New Physics Scale of R_K and R_{K^*}

unitarity bound	$\frac{4\pi}{\Lambda_{\rm NP}^2}(\bar{s}\gamma_\nu P_L b)(\bar{\mu}\gamma^\nu \mu)$	$\Lambda_{\rm NP} \simeq 120~\text{TeV} \times (C_9^{\rm NP})^{-1/2}$
generic tree	$\frac{1}{\Lambda_{\rm NP}^2}(\bar{s}\gamma_\nu P_L b)(\bar{\mu}\gamma^\nu \mu)$	$\Lambda_{\rm NP} \simeq 35~\text{TeV} \times (C_9^{\rm NP})^{-1/2}$
MFV tree	$\frac{1}{\Lambda_{\rm NP}^2}\, V_{tb} V_{ts}^* \,(\bar{s}\gamma_\nu P_L b)(\bar{\mu}\gamma^\nu \mu)$	$\Lambda_{\rm NP} \simeq 7~\text{TeV} \times (C_9^{\rm NP})^{-1/2}$
generic loop	$\frac{1}{\Lambda_{\rm NP}^2}\frac{1}{16\pi^2}(\bar{s}\gamma_\nu P_L b)(\bar{\mu}\gamma^\nu \mu)$	$\Lambda_{\rm NP} \simeq 3~\text{TeV} \times (C_9^{\rm NP})^{-1/2}$
MFV loop	$\frac{1}{\Lambda_{\rm NP}^2}\frac{1}{16\pi^2}\, V_{tb} V_{ts}^* \,(\bar{s}\gamma_\nu P_L b)(\bar{\mu}\gamma^\nu \mu)$	$\Lambda_{\rm NP} \simeq 0.6~\text{TeV} \times (C_9^{\rm NP})^{-1/2}$

(MFV = Minimal Flavor Violation)

$$\mathcal{H}_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{cb} \mathcal{O}_{V_L} + \frac{1}{\Lambda^2} \sum_i C_i \mathcal{O}_i$$



$\mathcal{O}_i$ = contact interactions
with vector, scalar
or tensor currents

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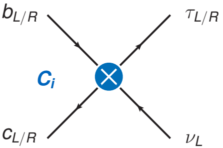
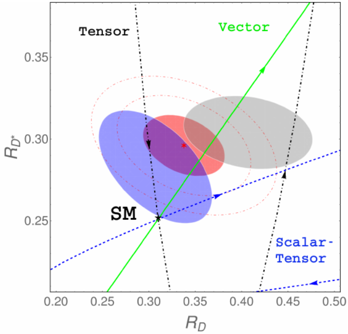


$\mathcal{O}_i$ = contact interactions
with vector, scalar
or tensor currents

rescaling of the SM vector operator fits the data best

combinations of operators are also possible

Shi et al. 1905.08498



(also Murgui et al. 1904.09311, Asadi, Shih 1905.03311, Cheung et al. 2002.07272, ...)

The New Physics Scale of R_D and R_{D^*}

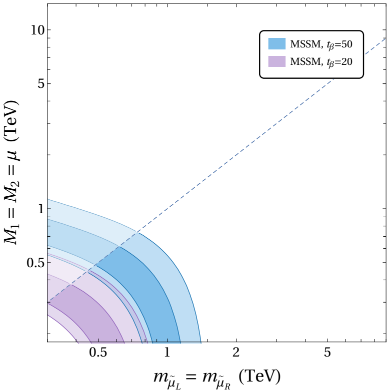
unitarity bound	$\frac{4\pi}{\Lambda_{\text{NP}}^2}(\bar{c}\gamma_\nu P_L b)(\bar{\tau}\gamma^\nu P_L \nu)$	$\Lambda_{\text{NP}} \simeq 8.4$ TeV
generic tree	$\frac{1}{\Lambda_{\text{NP}}^2}(\bar{c}\gamma_\nu P_L b)(\bar{\tau}\gamma^\nu P_L \nu)$	$\Lambda_{\text{NP}} \simeq 2.4$ TeV
MFV tree	$\frac{1}{\Lambda_{\text{NP}}^2}\, V_{cb}\, (\bar{c}\gamma_\nu P_L b)(\bar{\tau}\gamma^\nu P_L \nu)$	$\Lambda_{\text{NP}} \simeq 0.5$ TeV

(MFV = Minimal Flavor Violation)

The Flavor Anomalies in the MSSM

The Anomalous Magnetic Moment in the MSSM

- It is very well known that the MSSM can give sizeable contributions to $(g-2)_\mu$ via $\tan\beta$ enhanced smuon chargino/neutralino loops
  (talks by John Ellis, Sven Heinemeyer)
- Smuons, charginos, neutralinos need to be pretty light
- Compressed spectra to avoid exising LHC constraints
- Good discovery prospects at the high luminosity LHC and e^+e^- colliders (ILC, CLIC)



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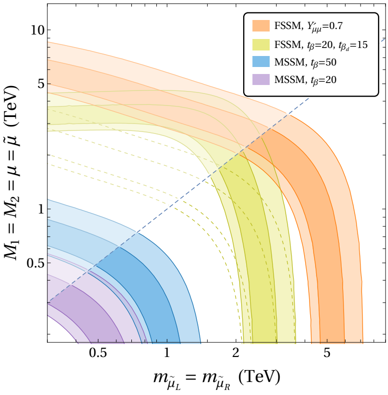
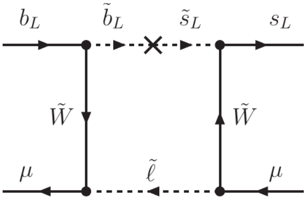


- With extended SUSY Higgs sectors, smuons, charginos, neutralinos can be significantly heavier WA, Gadam, Gori, Hamer 2104.08293 (→ backup slides)

R_K and R_{K^*} in the MSSM



WA, Straub

1308.1501, 1411.3161

- only way to get lepton flavor non universal contribution to rare $b \to s\ell\ell$ decays is through box diagrams with light winos (or Binos) and large non-universality in slepton masses.
- requires an extremely light spectrum to get $C_9^{bs\mu\mu} \sim -0.5$:

  winos and smuons around 100 GeV;
  sbottoms around 500 GeV;

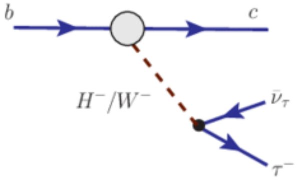
  very challenging to hide this at the LHC...

- There are tree level contributions to $B \to D^{(*)}\tau\nu$ from charged Higgs exchange

$$\frac{R_D}{R_D^{SM}} \sim 1 - 1.5 \frac{m_\tau m_b}{m_{H^\pm}^2} \tan^2\beta$$

$$\frac{R_{D^*}}{R_{D^*}^{SM}} \sim 1 - 0.12 \frac{m_\tau m_b}{m_{H^\pm}^2} \tan^2\beta$$

- Effect goes in the wrong direction and is much smaller for R_{D^*}



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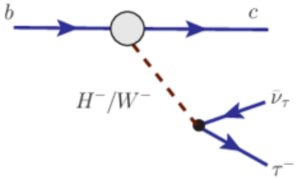
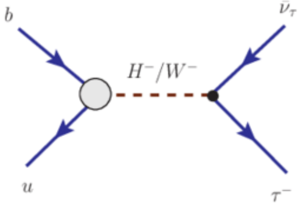
- Effect goes in the wrong direction and is much smaller for R_{D^*}
- Correlated with effect in $B \to \tau\nu$

$$\frac{\text{BR}(B \to \tau\nu)}{\text{BR}(B \to \tau\nu)_{\text{SM}}} \simeq \left(1 - \frac{m_B^2}{m_{H^\pm}^2} \tan^2\beta\right)^2$$

$\Rightarrow$ Can't explain $R_{D^{(*)}}$ with charged Higgs exchange in the MSSM





The Flavor Anomalies and R-Parity Violation

The MSSM with R-Parity Violation

(see talk by Herbi Dreiner)

- give up on a dark matter candidate, but open up possibilities to address the flavor anomalies

  Pragmatic phenomenological approach:

- consider the lepton number violating *LQD* and *LLE* interactions (no baryon number violating *UDD* interactions to avoid constraints from proton decay)

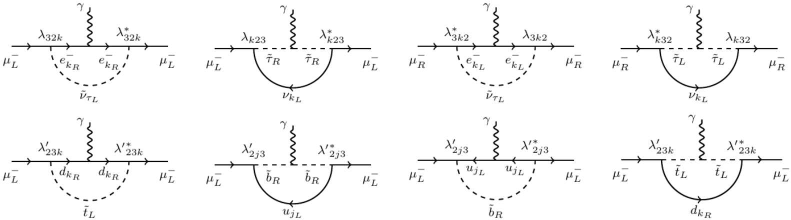
$$\mathcal{L}_{LQD} = \lambda'_{ijk}\left[\widetilde{\nu}_{iL}\bar{d}_{kR}d_{jL} + \widetilde{d}_{jL}\bar{d}_{kR}\nu_{iL} + \widetilde{d}^*_{kR}\bar{\nu}^c_{iL}d_{jL} - \widetilde{e}_{iL}\bar{d}_{kR}u_{jL} - \widetilde{u}_{jL}\bar{d}_{kR}e_{iL} - \widetilde{d}^*_{kR}\bar{e}^c_{iL}u_{jL}\right] + \text{H.c.}$$

$$\mathcal{L}_{LLE} = \frac{1}{2}\lambda_{ijk}\left[\widetilde{\nu}_{iL}\bar{e}_{kR}e_{jL} + \widetilde{e}_{jL}\bar{e}_{kR}\nu_{iL} + \widetilde{e}^*_{kR}\bar{\nu}^c_{iL}e_{jL} - (i \leftrightarrow j)\right] + \text{H.c.}$$

- assume that only the 3rd generation sfermions are light
  $\Rightarrow$ 7 λ couplings and 19 λ' couplings are relevant

$\rightarrow$ RPV3 (WA, Dev, Soni 1704.06659; WA, Dev, Soni, Sui 2002.12910; ...)

The Anomalous Magnetic Moment with RPV3



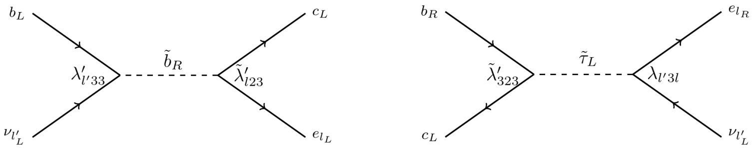
Kim, Kyae, Lee hep-ph/0103054; ...

- 1-loop contributions from λ' and λ couplings
  (in addition to the standard MSSM contributions)

$$\Delta a_\mu = \frac{m_\mu^2}{96\pi^2} \sum_{k=1}^{3} \left(\frac{2(|\lambda_{32k}|^2 + |\lambda_{3k2}|^2)}{m^2_{\tilde{\nu}_\tau}} - \frac{|\lambda_{3k2}|^2}{m^2_{\tilde{\tau}_L}} - \frac{|\lambda_{k23}|^2}{m^2_{\tilde{\tau}_R}} + \frac{3|\lambda'_{2k3}|^2}{m^2_{\tilde{b}_R}} \right)$$

- No $\tan\beta$ enhancement $\rightarrow$ need light sbottoms and/or sneutrinos with large couplings to get a relevant contribution in the right direction

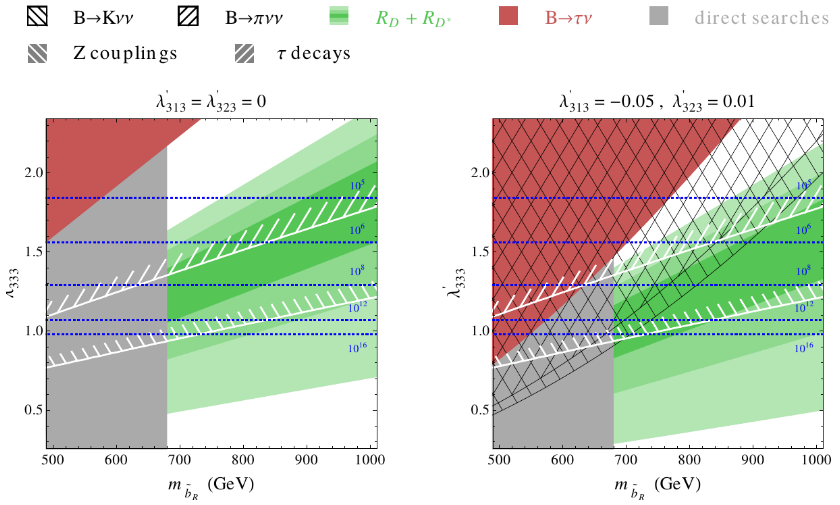
R_D and R_{D^*} with RPV3



Deshpande, He 1608.04817; WA, Dev, Soni 1704.06659; ...

- Tree level contributions from sbottom or stau exchange
- Stau behaves like a charged Higgs (but its couplings are less constrained). Stau contribution disfavored by $B_c \to \tau\nu$ branching ratio and kinematic distributions in $B \to D^{(*)}\tau\nu$.
- Sbottom behaves like a leptoquark. Chirality structure as prefered by model independent fits (Shi et al. 1905.08498; Murgui et al. 1904.09311; Asadi, Shih 1905.03311; Cheung et al. 2002.07272; ...)
- Can address the $R_{D^{(*)}}$ anomalies for sbottom masses $O(1\text{ TeV})$ and couplings $\lambda' \sim O(1)$
- need to be careful to keep $\mu - e$ universality in $b \to c\ell\nu$

Viable Parameter Space

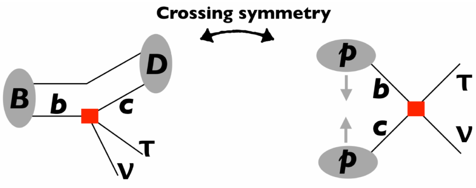


WA, Dev, Soni 1704.06659

Collider Signatures of $R_{D^{(*)}}$ Explanations

Expect non-standard
mono-tau production
at the LHC

(possibly in association
with b-jets)



WA, Dev, Soni 1704.06659; Greljo et al. 1811.07920;
Marzocca et al. 2008.07541; ...

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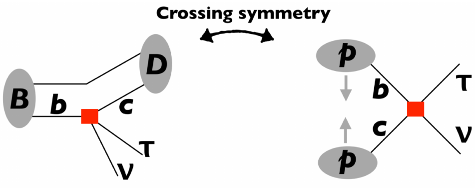
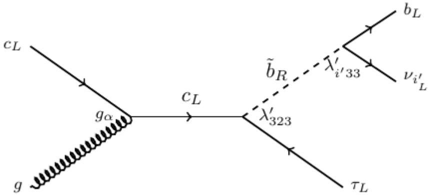
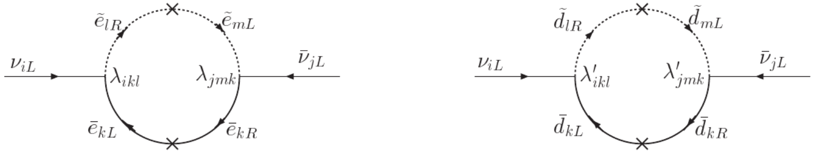


WA, Dev, Soni 1704.06659; Greljo et al. 1811.07920;
Marzocca et al. 2008.07541; ...

- In RPV3, look for sbottom production $gc \to \tilde{b}\tau \to b\nu\tau$





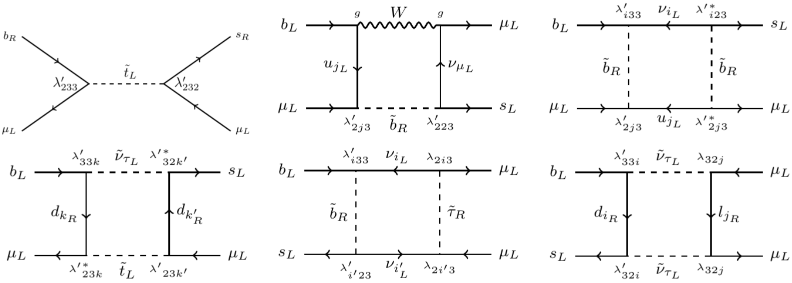
Barbier et al. hep-ph/0406039; WA, Dev, Soni 1704.06659

- The RPV couplings needed to address R_D and R_{D^*} give also 1-loop contributions to Majorana neutrino masses

$$(\hat{M}_\nu)_{ij} = (\hat{M}_\nu)_{ij}^{\text{tree}} + \frac{3}{8\pi^2}\frac{m_b^2(A_b - \mu\tan\beta)}{m_{\tilde{b}}^2}\lambda'_{i33}\lambda'_{j33} + \frac{1}{8\pi^2}\frac{m_\tau^2(A_\tau - \mu\tan\beta)}{m_{\tilde{\tau}}^2}\lambda_{i33}\lambda_{j33} + \dots$$

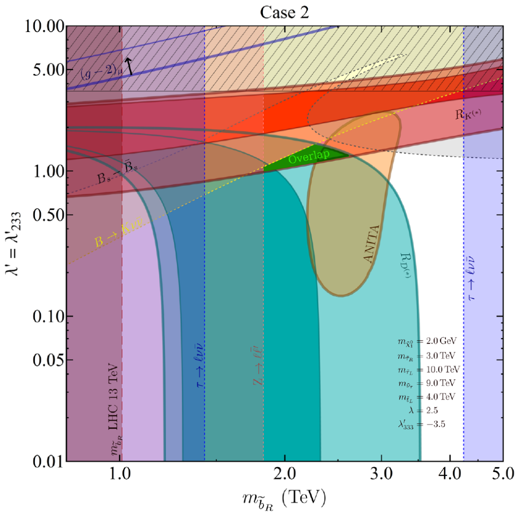
- Generic size of neutrino masses for sbottom/stau masses of $O(1\text{ TeV})$ and couplings of $O(1)$ is $\sim$ 0.1 MeV

- Need cancellation to obtain sub-eV neutrino masses



Das et al. 1705.09188; Earl Gregoire 1806.01343; Trifinopoulos 1807.01638; Hu, Huang 1912.03676; WA, Dev, Soni, Sui 2002.12910; Bardhan et al. 2107.10163

- Tree level contribution from stop exchange have the wrong chirality
- Several loop contributions with the right chirality and $C_9 = -C_{10}$
- Both λ and λ' couplings can be involved



WA, Dev, Soni, Sui 2002.12910

- We consider a few benchmark scenarios
- We include a very long list of constraints:

  meson mixing;

  rare decays;

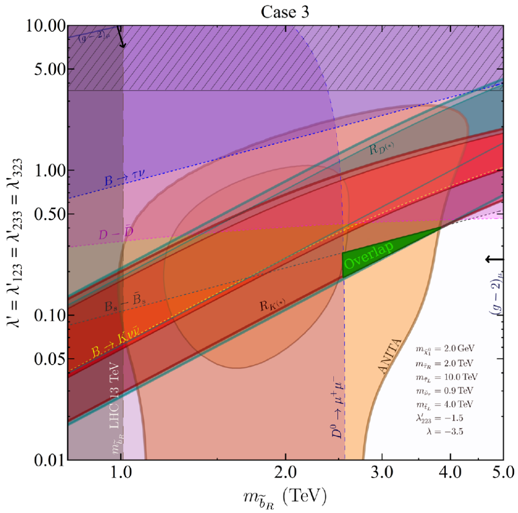
  Z decays;

  lepton flavor violation;

  direct LHC searches;

  ...
- Agreement with the anomalies at the border of many constraints

Combined Explanations of the Anomalies in RPV3



WA, Dev, Soni, Sui 2002.12910

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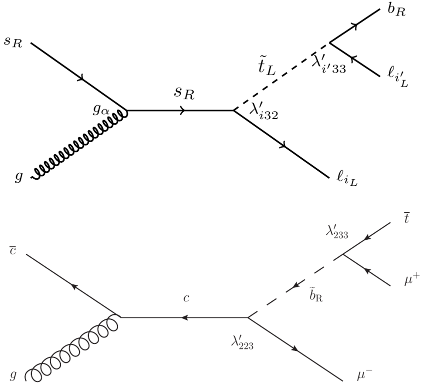
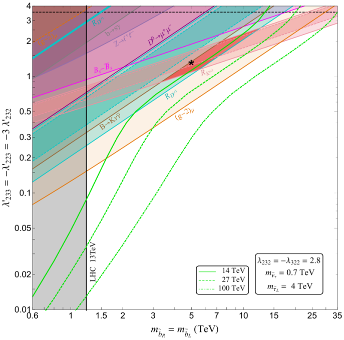
Collider Signatures of $R_{K^{(*)}}$ Explanations

- Based on crossing symmetry expect the processes $bs \to \ell\ell$, $gb \to s\ell\ell$, and $gs \to b\ell\ell$.
- In RPV3: for example single stop production giving a $b\mu$ resonance, or single sbottom production giving a $t\mu$ resonance.





Dev, Soni, Xu 2106.15647

Summary

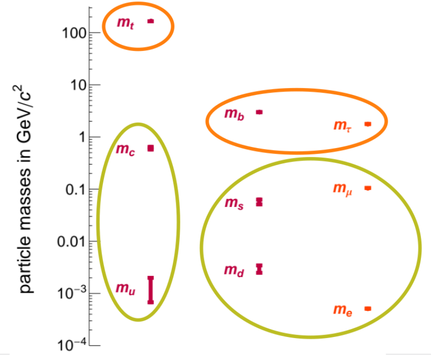
- Rare B decays show persistent discrepancies with SM predictions.
- If significance of LFU violation ($R_{D^{(*)}}$ and $R_{K^{(*)}}$) continues to grow with more statistics $\Rightarrow$ clear indication of new physics. (Recent updates by LHCb are reassuring!)
- It's not possible to explain $R_{D^{(*)}}$ and $R_{K^{(*)}}$ in the MSSM.
- In RPV3, explanations of $R_{D^{(*)}}$ and $R_{K^{(*)}}$ are borderline compatible with constraints.
- Collider signatures:
  "single production of flavored leptoquarks".

Back Up

The FSSM Setup

- Extended SUSY Higgs sector with 4 Higgs doublets H_u, H'_u, H_d, H'_d
- The superpotential of the model is

$$W = \mu_1 \hat{H}_u \hat{H}_d + \mu_2 \hat{H}'_u \hat{H}'_d + \mu_3 \hat{H}'_u \hat{H}_d + \mu_4 \hat{H}_u \hat{H}'_d$$
$$(Y_u \hat{H}_u + Y'_u \hat{H}'_u) \hat{Q} \hat{U}^c + (Y_d \hat{H}_d + Y'_d \hat{H}'_d) \hat{Q} \hat{D}^c + (Y_\ell \hat{H}_d + Y'_\ell \hat{H}'_d) \hat{L} \hat{E}^c$$



- Four μ terms
- Third generation gets mass from H_u, H_d
- First and second generation get mass from H'_u, H'_d

FSSM = Flavorful Supersymmetric Standard Model

Muon and Smuon Masses in the FSSM

4 Higgs doublets $\Rightarrow$ 4 vevs v_u, v'_u, v_d, v'_d, with $v_u^2 + {v'_u}^2 + v_d^2 + {v'_d}^2 = v^2$

- Useful to introduce the ratios

$$\tan\beta = \frac{v_u}{v_d} , \quad \tan\beta_u = \frac{v_u}{v'_u} , \quad \tan\beta_d = \frac{v_d}{v'_d}$$

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- $\tan\beta_d$ controls the size of muon Yukawa (independently of the tau and bottom Yukawas)

$$Y'_{\mu\mu} \simeq \sqrt{2}\frac{m_\mu}{v}\frac{\tan\beta\tan\beta_d}{1+\epsilon_\ell\tan\beta\tan\beta_d}~, \qquad Y_\tau \simeq \sqrt{2}\frac{m_\tau}{v}\frac{\tan\beta}{1+\epsilon_\tau\tan\beta}$$

- Muon Yukawa $Y'_{\mu\mu}$ can be $\mathcal{O}(1)$ without running into Landau poles

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- Muon Yukawa $Y'_{\mu\mu}$ can be $\mathcal{O}(1)$ without running into Landau poles

- $\tan\beta_d$ also boosts left-right mixing of smuons

$$M^2_{\tilde{\mu}} \simeq \begin{pmatrix} m^2_{\tilde{\mu}_L} & -m_\mu\mu_4\frac{\tan\beta\tan\beta_d}{1+\epsilon_\ell\tan\beta\tan\beta_d} \\ -m_\mu\mu_4\frac{\tan\beta\tan\beta_d}{1+\epsilon_\ell\tan\beta\tan\beta_d} & m^2_{\tilde{\mu}_R} \end{pmatrix}$$

Chargino and Neutralino Spectrum in the FSSM

- 4 Higgsinos + Winos + Bino $\Rightarrow$ 3 charginos + 6 neutralinos
- Chargino mass matrix

$$M_{\chi^\pm} = \begin{pmatrix} M_2 & \frac{g}{\sqrt{2}} v_u & \frac{g}{\sqrt{2}} v'_u \\ \frac{g}{\sqrt{2}} v_d & \mu_1 & \mu_3 \\ \frac{g}{\sqrt{2}} v'_d & \mu_4 & \mu_2 \end{pmatrix}$$

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- It is convenient to first diagonalize the Higgsino block

$$\begin{pmatrix} \cos\theta_d & \sin\theta_d \\ -\sin\theta_d & \cos\theta_d \end{pmatrix} \begin{pmatrix} \mu_1 & \mu_3 \\ \mu_4 & \mu_2 \end{pmatrix} \begin{pmatrix} \cos\theta_u & \sin\theta_u \\ -\sin\theta_u & \cos\theta_u \end{pmatrix} = \begin{pmatrix} \mu & 0 \\ 0 & \tilde{\mu} \end{pmatrix}$$

Generically expect the rotation angles θ_u and θ_d to be $\mathcal{O}(1)$

Chargino and Neutralino Spectrum in the FSSM

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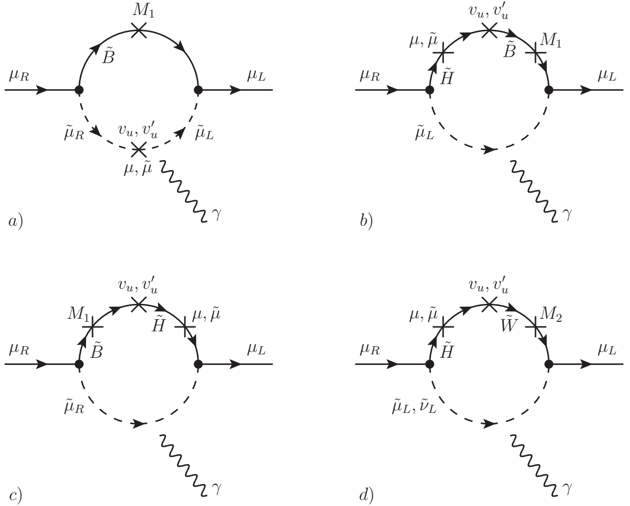
  Generically expect the rotation angles θ_u and θ_d to be $\mathcal{O}(1)$
- Remaining off-diagonal entries are of the order of the electroweak scale and can be treated perturbatively
- Analogous treatment for the neutralinos
- The $\tilde{H}_d'$ component of the charginos and neutralinos can have $\mathcal{O}(1)$ coupling to muons

$(g-2)_\mu$ in the FSSM



$(g-2)_\mu$ in the FSSM

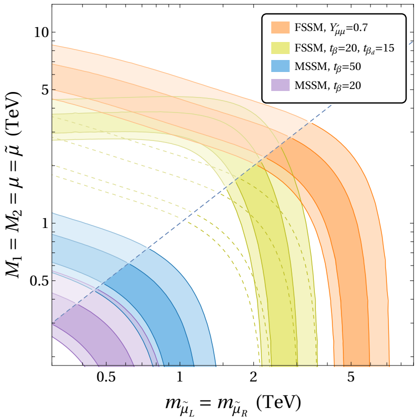
- Bino and Wino contributions have a structure that is analogous to the MSSM

$$\Delta a_\mu^{\tilde{b}} \sim \frac{g'^2}{16\pi^2} \frac{m_\mu^2}{m_{\tilde{\mu}}^2} \frac{M_1}{m_{\tilde{\mu}}^2} \left(\mu \sin\theta_d \cos\theta_u + \tilde{\mu} \cos\theta_d \sin\theta_u\right) \frac{1}{12} \frac{\tan\beta \tan\beta_d}{1 + \epsilon_\ell \tan\beta \tan\beta_d}$$

$$\Delta a_\mu^{\tilde{w}} \sim \frac{g^2}{16\pi^2} \frac{m_\mu^2}{m_{\tilde{\mu}}^2} \frac{M_2}{m_{\tilde{\mu}}^2} \left(\mu \sin\theta_d \cos\theta_u + \tilde{\mu} \cos\theta_d \sin\theta_u\right) \frac{5}{12} \frac{\tan\beta \tan\beta_d}{1 + \epsilon_\ell \tan\beta \tan\beta_d}$$

- Contributions from the Higgsinos with mass μ and the Higgsinos with mass $\tilde{\mu}$
- Main qualitative difference to the MSSM: additional enhancement by $\tan\beta_d$

WA, Gadam, Gori, Hamer 2104.08293



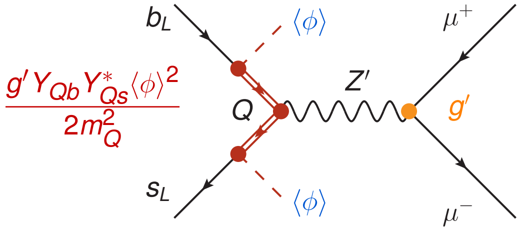
- Plot assumes $\mathcal{O}(1)$ Higgsino mixing: $\theta_u = \theta_d = \pi/2$
- SUSY particles can be several TeV and can still explain the $(g-2)_\mu$ discrepancy

$$\Delta a_\mu \simeq 240 \times 10^{-11} \times \left(\frac{Y'_{\mu\mu}}{0.7}\right)^2 \left(\frac{2.5\text{ TeV}}{m_{\text{SUSY}}}\right)^2$$

My Favorite Model for R_K and R_{K^*}

Z' based on gauging $L_\mu - L_\tau$ (He, Joshi, Lew, Volkas PRD 43, 22-24)
with effective flavor violating couplings to quarks

WA, Gori, Pospelov, Yavin 1403.1269; WA, Yavin 1508.07009



Q: heavy vectorlike fermions with mass $\sim 1 - 10$ TeV
ϕ: scalar that breaks $L_\mu - L_\tau$

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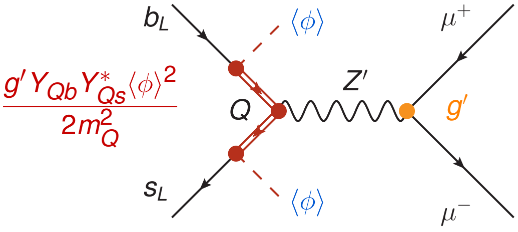

predicted Lepton Universality Violation!

Q: heavy vectorlike fermions with mass $\sim 1 - 10$ TeV
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Neutrino Tridents

B_s mixing

$(g-2)_\mu$

νe scattering

$Z \to \ell\ell$

$Z \to 4\mu$

$e^+e^- \to 4\mu$

WA, Gori, Martin-Albo, Sousa, Wallbank 1902.06765