Hint of SUSY in Flavor Anomalies?

Bhupal Dev

Washington University in St. Louis

based on work with Wolfgang Altmannshofer (UCSC), Amarjit Soni (BNL), Yicong Sui (WU) and Fang Xu (WU),

arXiv: 1704.06659 (PRD '17); 2002.12910 (PRD '20); 2105.abcde

Theory Seminar

Fermilab

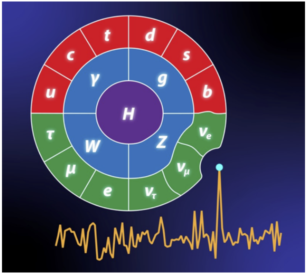
May 13, 2021

Outline

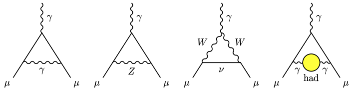
- Flavor Anomalies
- The RPV3 Framework
- Benchmark Points
- Collider Signals
- Conclusion

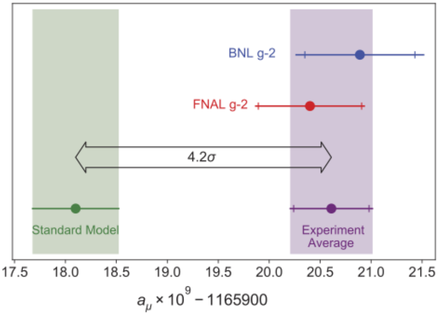
An Era of Anomalies

- A growing list of “anomalies”.
- See here for a repository (please add your favorite anomaly or model, if missing).
- Could be due to
  - statistical fluctuations (e.g. 750 GeV $\gamma\gamma$),
  - systematics or background uncertainties (e.g. KOTO),
  - experimental error (e.g. OPERA),
  - unknown issues (e.g. DAMA?), or
  - **signal of new physics?**
- A good driver of scientific creativity (not just ‘ambulance-chasing’).

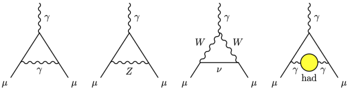


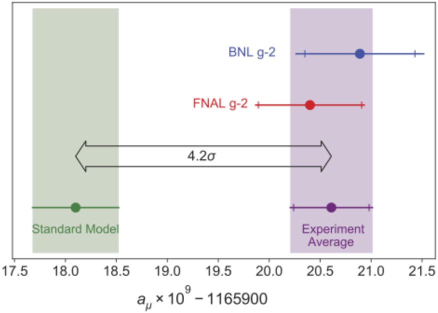
Muon $g - 2$ Anomaly

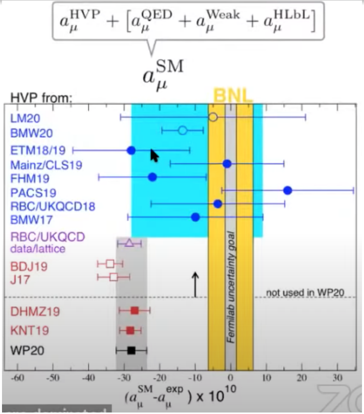




Muon $g-2$ Anomaly





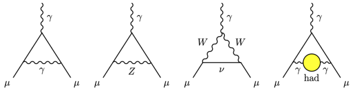


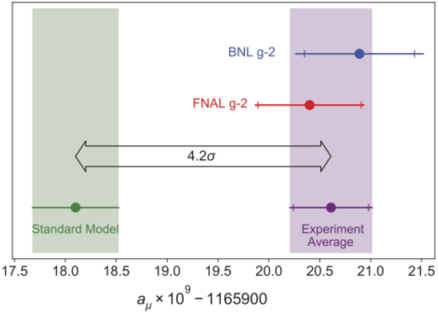
[Fermilab talk by A. El-Khadra]

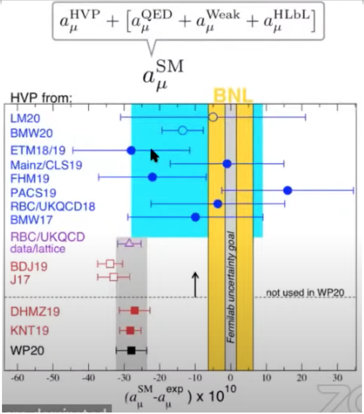
$$a_\mu^{\rm exp} = 116592061(41) \times 10^{-11} \quad [2104.03281\ (\text{PRL}'21)]$$

$$a_\mu^{\rm SM} = 116591810(43) \times 10^{-11} \quad [2006.04822\ (\text{Phys.Rep.}'20)]$$

Muon $g-2$ Anomaly







[Fermilab talk by A. El-Khadra]

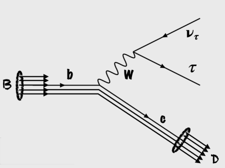
$$a_\mu^{\mathrm{exp}} = 116592061(41) \times 10^{-11} \quad [2104.03281\ (\mathrm{PRL}'21)]$$

$$a_\mu^{\mathrm{SM}} = 116591810(43) \times 10^{-11} \quad [2006.04822\ (\mathrm{Phys.Rep.}'20)]$$

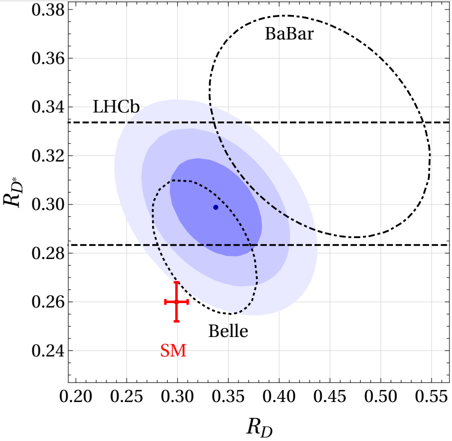
- If a change in HVP brought a_μ^{SM} closer to a_μ^{exp}, problems will arise in the global EW fit. [Crivellin, Hoferichter, Manzari, Montull, 2003.04886 (PRL '20)]]
- (Related?) Unresolved issues in the electron $g-2$ sector. [Parker, Yu, Zhong, Estey, Mueller, 1812.04130 (Science '19); Morel, Yao, Clade, Guellati-Khelifa (Nature '20)]

$R_{D^{(*)}}$ Anomaly

$$R_{D^{(*)}} = \frac{\mathrm{BR}(B \to D^{(*)}\tau\nu)}{\mathrm{BR}(B \to D^{(*)}\ell\nu)} \quad (\text{with } \ell = e, \mu)$$



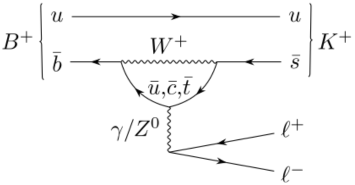
Experiment	Tag method	τ decay mode	R_D	R_{D^*}	$R_{J/\psi}$
Babar (2012) [1]	hadronic	$\ell\nu\nu$	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.0.018$	
Belle (2015) [2]	hadronic	$\ell\nu\nu$	$0.375 \pm 0.064 \pm 0.026$	$0.293 \pm 0.038 \pm 0.015$	
LHCb (2015) [5]	hadronic	$\ell\nu\nu$	-	$0.336 \pm 0.027 \pm 0.030$	
Belle (2016) [2]	semileptonic	$\ell\nu\nu$	-	$0.302 \pm 0.030 \pm 0.011$	
Belle (2017) [3]	hadronic	$\pi(\rho)\nu$	-	$0.270 \pm 0.035 \pm 0.027$	
LHCb (2017) [6]	hadronic	$3\pi\nu$	-	$0.291 \pm 0.019 \pm 0.029$	
Belle (2019) [4]	semileptonic	$\ell\nu\nu$	$0.307 \pm 0.037 \pm 0.016$	$0.283 \pm 0.018 \pm 0.014$	
LHCb (2016) [67]	hadronic	$\ell\nu\nu$	-	-	$0.71 \pm 0.17 \pm 0.18$
SM	-	-	0.299 ± 0.011 [63]	0.260 ± 0.008 [64]	0.26 ± 0.02 [68]

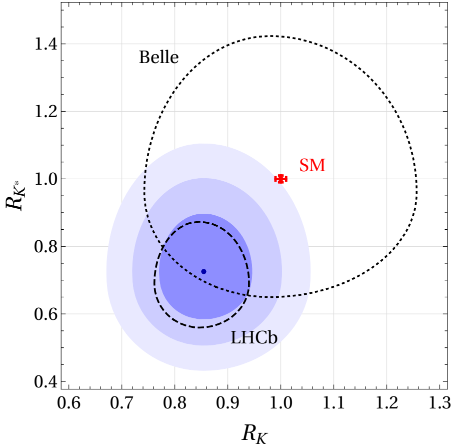


[Altmannshofer, BD, Soni, Sui, 2002.12910 (PRD '20)]

- Flavor Changing Charged Current – happens at tree-level in the SM (only CKM-suppressed).
- *All* experimental measurements to date are consistently *above* the SM prediction.
- 3.3σ net discrepancy.

$$\boxed{R_{K^{(*)}} = \frac{\mathrm{BR}(B \to K^{(*)}\mu^+\mu^-)}{\mathrm{BR}(B \to K^{(*)}e^+e^-)}}$$





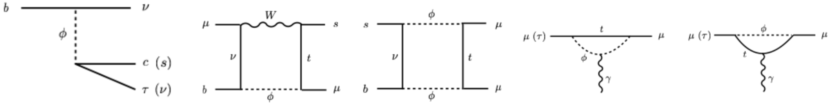
- Flavor Changing Neutral Current – loop-suppressed in the SM.
- Recent update on R_K measurement from LHCb:

$$R_K^{\mathrm{new}} = 0.846^{+0.042+0.013}_{-0.039-0.012} \quad [2103.11769]$$
$$R_K^{\mathrm{old}} = 0.846^{+0.060+0.016}_{-0.054-0.014} \quad [1903.09252\ (\mathrm{PRL}'19)].$$

- 3.4σ net discrepancy.

New Physics Solution to All Flavor Anomalies

- Single scalar leptoquark solution [Bauer, Neubert, 1511.01900 (PRL '16)]

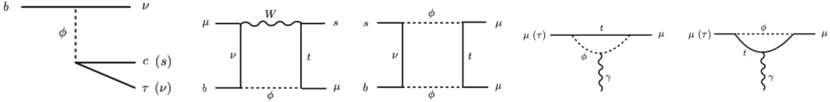


- Now disfavored by global fits (including $b \to s\mu^+\mu^-$ observables, as well as LHC constraints). [Angelescu, Becirevic, Faroughy, Jaffredo, Sumensari, 2103.12504]

Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
S_3 $(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$	✓	✗	✗
S_1 $(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$	✗	✓	✗
R_2 $(\mathbf{3}, \mathbf{2}, 7/6)$	✗	✓	✗
U_1 $(\mathbf{3}, \mathbf{1}, 2/3)$	✓	✓	✓
U_3 $(\mathbf{3}, \mathbf{3}, 2/3)$	✓	✗	✗

New Physics Solution to All Flavor Anomalies

- Single scalar leptoquark solution [Bauer, Neubert, 1511.01900 (PRL '16)]



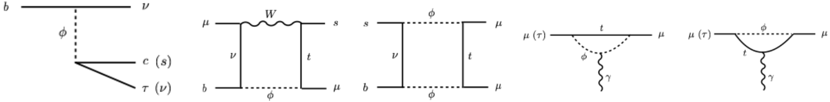
- Now disfavored by global fits (including $b \to s\mu^+\mu^-$ observables, as well as LHC constraints). [Angelescu, Becirevic, Faroughy, Jaffredo, Sumensari, 2103.12504]

Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
S_3 $(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$	✓	✗	✗
S_1 $(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$	✗	✓	✗
R_2 $(\mathbf{3}, \mathbf{2}, 7/6)$	✗	✓	✗
U_1 $(\mathbf{3}, \mathbf{1}, 2/3)$	✓	✓	✓
U_3 $(\mathbf{3}, \mathbf{3}, 2/3)$	✓	✗	✗

- Vector LQ must be embedded into some UV-completion $\Longrightarrow$ Loses minimality.
- Solutions with more than one scalar LQ possible. [Chen, Nomura, Okada (1703.03251); Bigaran, Gargalionis, Volkas (1906.01870); Saad (2005.04352); Babu, BD, Jana, Thapa (2009.01771)]

New Physics Solution to All Flavor Anomalies

- Single scalar leptoquark solution [Bauer, Neubert, 1511.01900 (PRL '16)]



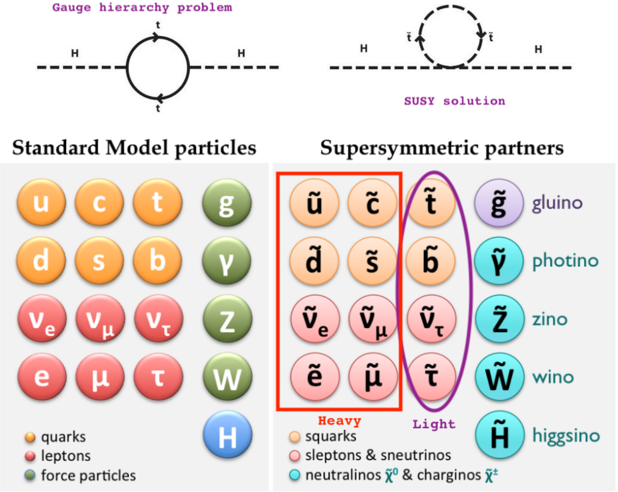
- Now disfavored by global fits (including $b \to s\mu^+\mu^-$ observables, as well as LHC constraints). [Angelescu, Becirevic, Faroughy, Jaffredo, Sumensari, 2103.12504]

Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
S_3 $(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$	✓	✗	✗
S_1 $(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$	✗	✓	✗
R_2 $(\mathbf{3}, \mathbf{2}, 7/6)$	✗	✓	✗
U_1 $(\mathbf{3}, \mathbf{1}, 2/3)$	✓	✓	✓
U_3 $(\mathbf{3}, \mathbf{3}, 2/3)$	✓	✗	✗

- Vector LQ must be embedded into some UV-completion $\Longrightarrow$ Loses minimality.
- Solutions with more than one scalar LQ possible. [Chen, Nomura, Okada (1703.03251); Bigaran, Gargalionis, Volkas (1906.01870); Saad (2005.04352); Babu, BD, Jana, Thapa (2009.01771)]

This talk: A minimal RPV-SUSY solution

Why SUSY?



Natural SUSY

[Brust, Katz, Lawrence, Sundrum, 1110.6670 (JHEP '12); Papucci, Ruderman, Weiler, 1110.6926 (JHEP '12)]

Why RPV SUSY?

- More natural to include RPV couplings, rather than imposing *R*-parity by hand.

  [Brust, Katz, Lawrence, Sundrum, 1110.6670 (JHEP ’12)]
- **RPC vs. RPV** – proton decay, dark matter, unification, FCNC.
- Third generation may be special.
- **RPV3**: RPV SUSY with light 3rd-generation sfermions.

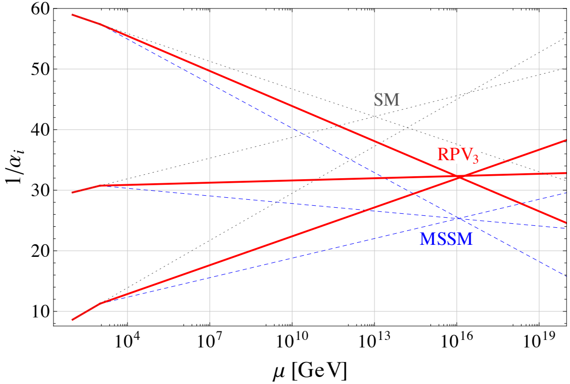
  [Altmannshofer, BD, Soni, 1704.06659 (PRD ’17)]

Why RPV SUSY?

- More natural to include RPV couplings, rather than imposing *R*-parity by hand.

  [Brust, Katz, Lawrence, Sundrum, 1110.6670 (JHEP '12)]
- **RPC vs. RPV** – proton decay, dark matter, unification, FCNC.
- Third generation may be special.
- **RPV3**: RPV SUSY with light 3rd-generation sfermions.

  [Altmannshofer, BD, Soni, 1704.06659 (PRD '17)]



Still preserves coupling unification.

B-anomalies in RPV-SUSY

- Can naturally accommodate $R_{D^{(*)}}$ ($b \to c\tau\nu$) via *LQD* interactions. [Deshpande, He (EPJC '17); Altmannshofer, BD, Soni (PRD '17); Trifinopoulos (EPJC '18); Hu, Li, Muramatsu, Yang (PRD '19)]

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

- Can *simultaneously* explain $R_{K^{(*)}}$ ($b \to s\ell\ell$) by invoking *LLE* interactions, together with *LQD*. [Das, Hati, Kumar, Mahajan (PRD '17); Earl, Grégoire (JHEP '18); Trifinopoulos (EPJC '18); Hu, Huang (PRD '20); Altmannshofer, BD, Soni, Sui (PRD '20)]

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

- Muon $g-2$ from both *LQD* and *LLE* terms.

B-anomalies in RPV-SUSY

- Can naturally accommodate $R_{D^{(*)}}$ ($b \to c\tau\nu$) via *LQD* interactions. [Deshpande, He (EPJC '17); Altmannshofer, BD, Soni (PRD '17); Trifinopoulos (EPJC '18); Hu, Li, Muramatsu, Yang (PRD '19)]

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

- Can *simultaneously* explain $R_{K^{(*)}}$ ($b \to s\ell\ell$) by invoking *LLE* interactions, together with *LQD*. [Das, Hati, Kumar, Mahajan (PRD '17); Earl, Grégoire (JHEP '18); Trifinopoulos (EPJC '18); Hu, Huang (PRD '20); Altmannshofer, BD, Soni, Sui (PRD '20)]

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

- Muon $g-2$ from both *LQD* and *LLE* terms.

- 27+9 independent coupling parameters.
- Restricting to RPV3 and using some ansatz, can limit the number of relevant independent λ' and λ couplings.
- Will consider three benchmark cases (CKM-like, symmetry-based, anarchic).

B-anomalies in RPV3

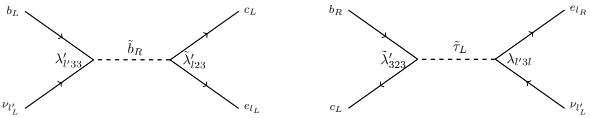


Figure: RPV3 contributions to $R_{D^{(*)}}$. [Deshpande, He (EPJC '17); Altmannshofer, BD, Soni (PRD '17); $\cdots$]

B-anomalies in RPV3

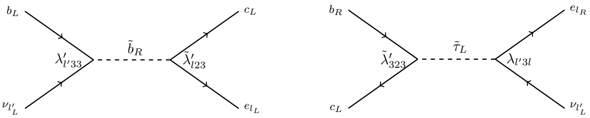


Figure: RPV3 contributions to $R_{D^{(*)}}$. [Deshpande, He (EPJC '17); Altmannshofer, BD, Soni (PRD '17); $\cdots$]

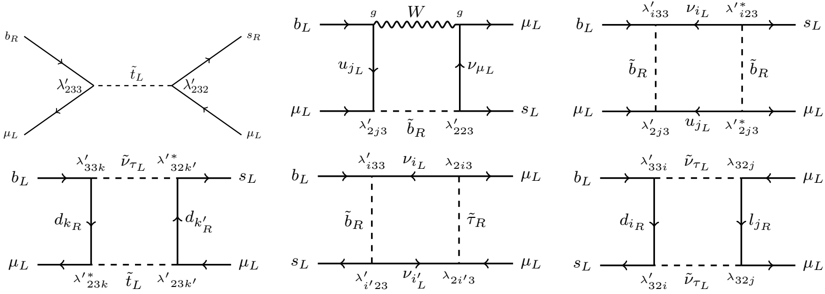


Figure: RPV3 contributions to $R_{K^{(*)}}$. [Das, Hati, Kumar, Mahajan (PRD '17); Trifinopoulos (EPJC '18); $\cdots$]

Muon $g-2$

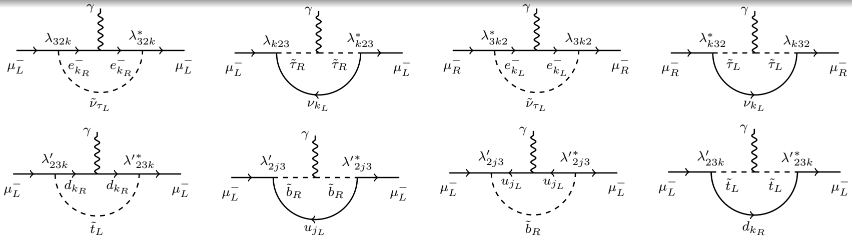


Figure: RPV3 contributions to $(g-2)_\mu$. [Kim, Kyae, Lee (PLB '01)]

Muon $g-2$

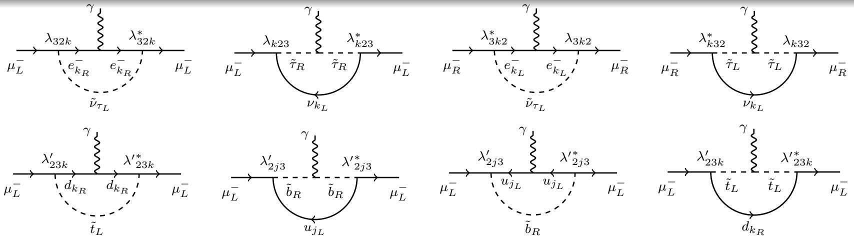


Figure: RPV3 contributions to $(g-2)_\mu$. [Kim, Kyae, Lee (PLB '01)]

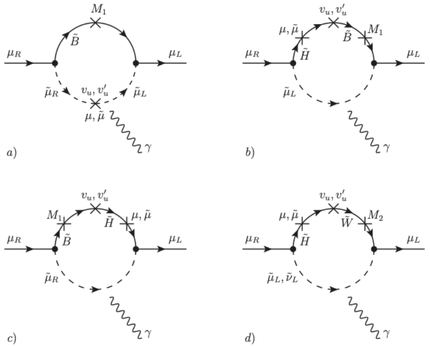


Figure: RPC contributions to $(g-2)_\mu$. [Moroi (PRD '96); Baum, Carena, Shah, Wagner (2104.03302)]

Three Benchmark Cases

- **Case 1: CKM-like Structure**

$$\lambda'_{ijk} = \lambda'_{333}\,\epsilon^{(3-i)+(3-j)+(3-k)}\,, \qquad \lambda_{ijk} = \lambda_{233}\,\epsilon^{(2-i)+(3-j)+(3-k)}\,.$$

Only 3 independent coupling parameters: $\{\lambda'_{333}, \lambda_{233}, \epsilon\}$.

Three Benchmark Cases

- **Case 1: CKM-like Structure**

$$\lambda'_{ijk} = \lambda'_{333}\,\epsilon^{(3-i)+(3-j)+(3-k)}\,, \qquad \lambda_{ijk} = \lambda_{233}\,\epsilon^{(2-i)+(3-j)+(3-k)}\,.$$

Only 3 independent coupling parameters: $\{\lambda'_{333}, \lambda_{233}, \epsilon\}$.

- **Case 2: $U(2)_q \times U(2)_\ell$ Flavor Symmetry**

$$\begin{aligned}
&\lambda'_{1jk} = \lambda'_{211} = \lambda'_{231} = \lambda'_{213} = \lambda'_{311} = \lambda'_{331} = \lambda'_{313} \simeq 0\,,\\
&\lambda'_{233} \simeq \lambda'\epsilon_\ell\,, \qquad \lambda'_{221} = \lambda'_{212} \simeq \lambda'\epsilon_\ell\epsilon'_q\,, \qquad \lambda'_{321} = \lambda'_{312} \simeq \lambda'\epsilon'_q\,,\\
&\lambda'_{222} = \lambda'_{223} = \lambda'_{232} \simeq \lambda'\epsilon_\ell\epsilon_q\,, \qquad \lambda'_{322} = \lambda'_{323} = \lambda'_{332} \simeq \lambda'\epsilon_q\,,
\end{aligned}$$

$$\begin{aligned}
&\lambda_{121} = \lambda_{131} = \lambda_{133} \simeq 0\,,\\
&\lambda_{123} = \lambda_{132} = \lambda_{231} \simeq \lambda\epsilon'_\ell\,, \quad \lambda_{232} \simeq \lambda\epsilon_{\ell S}\,, \quad \lambda_{122} \simeq \lambda\epsilon_\ell\epsilon'_\ell\,, \quad \lambda_{233} \simeq \lambda\epsilon_\ell\,,
\end{aligned}$$

where $\epsilon_q \approx m_s/m_b \simeq 0.025$, $\epsilon'_q \approx \epsilon_q\sqrt{m_d/m_s} \simeq 0.005$, $\epsilon_\ell \simeq 1$, $\epsilon'_\ell \simeq 0.004$ and $\epsilon_{\ell S} \simeq 0.06$ [Trifinopoulos (EPJC '18)]. Again, 3 independent couplings: $\{\lambda'_{333}, \lambda', \lambda\}$.

- **Case 1: CKM-like Structure**

$$\lambda'_{ijk} = \lambda'_{333}\,\epsilon^{(3-i)+(3-j)+(3-k)}\,, \qquad \lambda_{ijk} = \lambda_{233}\,\epsilon^{(2-i)+(3-j)+(3-k)}\,.$$

Only 3 independent coupling parameters: $\{\lambda'_{333}, \lambda_{233}, \epsilon\}$.

- **Case 2:** $U(2)_q \times U(2)_\ell$ **Flavor Symmetry**

$$\begin{aligned}
&\lambda'_{1jk} = \lambda'_{211} = \lambda'_{231} = \lambda'_{213} = \lambda'_{311} = \lambda'_{331} = \lambda'_{313} \simeq 0\,,\\
&\lambda'_{233} \simeq \lambda'\epsilon_\ell\,, \qquad \lambda'_{221} = \lambda'_{212} \simeq \lambda'\epsilon_\ell\epsilon'_q\,, \qquad \lambda'_{321} = \lambda'_{312} \simeq \lambda'\epsilon'_q\,,\\
&\lambda'_{222} = \lambda'_{223} = \lambda'_{232} \simeq \lambda'\epsilon_\ell\epsilon_q\,, \qquad \lambda'_{322} = \lambda'_{323} = \lambda'_{332} \simeq \lambda'\epsilon_q\,,
\end{aligned}$$

$$\begin{aligned}
&\lambda_{121} = \lambda_{131} = \lambda_{133} \simeq 0\,,\\
&\lambda_{123} = \lambda_{132} = \lambda_{231} \simeq \lambda\epsilon'_\ell\,, \quad \lambda_{232} \simeq \lambda\epsilon_{\ell S}\,, \quad \lambda_{122} \simeq \lambda\epsilon_\ell\epsilon'_\ell\,, \quad \lambda_{233} \simeq \lambda\epsilon_\ell\,,
\end{aligned}$$

where $\epsilon_q \approx m_s/m_b \simeq 0.025$, $\epsilon'_q \approx \epsilon_q\sqrt{m_d/m_s} \simeq 0.005$, $\epsilon_\ell \simeq 1$, $\epsilon'_\ell \simeq 0.004$ and $\epsilon_{\ell S} \simeq 0.06$ [Trifinopoulos (EPJC '18)]. Again, 3 independent couplings: $\{\lambda'_{333}, \lambda', \lambda\}$.

- **Case 3: No Symmetry.** Also choose 3 independent couplings:

$$\{\lambda'_{223}\,, \quad \lambda' \equiv \lambda'_{123} = \lambda'_{233} = \lambda'_{323}\,, \quad \lambda \equiv \lambda_{132} = \lambda_{231} = \lambda_{232}\}.$$

- In each case, five (six) free mass parameters: $\{m_{\tilde{b}_R}, m_{\tilde{t}_L}, m_{\tilde{\tau}_L}, m_{\tilde{\tau}_R}, m_{\tilde{\nu}_\tau}, (m_{\tilde{\chi}^0_1})\}$.

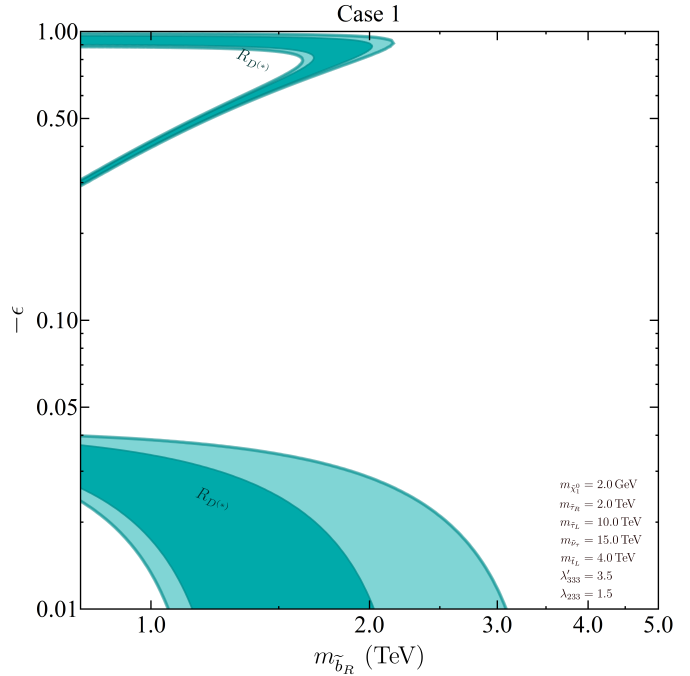
Parameter Dependence of Observables

Observable	Parameter dependence	Relevant terms
$R_{D^{(*)}}$	$\lambda'_{i33}, \lambda'_{3j3}, \lambda'_{2j3}, m_{\tilde{b}_R}$, $\lambda_{i33}, \lambda_{i32}, m_{\tilde{\tau}_L}$	$\frac{\lambda'_{i33}\cdot\lambda'_{3j3}}{m^2_{\tilde{b}_R}}, -\frac{\lambda'_{i33}\cdot\lambda'_{2j3}}{m^2_{\tilde{b}_R}}$, $\frac{\lambda_{i33}\cdot\lambda'_{3j3}}{m^2_{\tilde{\tau}_L}}, \frac{\lambda_{i32}\cdot\lambda'_{3j3}}{m^2_{\tilde{\tau}_L}}$
$R_{K^{(*)}}$	$\lambda'_{331}, \lambda'_{332}, \lambda'_{321}, \lambda'_{322}, \lambda'_{231}, \lambda'_{232}$, $\lambda'_{i33}, \lambda'_{i23}, \lambda'_{213}, \lambda'_{312}, \lambda_{32k}, \lambda_{3j2}$, $m_{\tilde{b}_R}, m_{\tilde{t}_L}, m_{\tilde{\tau}_R}$	$\frac{\lvert\lambda'_{233}\rvert^2}{m^2_{\tilde{b}_R}}$, $\frac{(\lambda'_{i33}\cdot\lambda'_{i23})\lvert\lambda'_{2j3}\rvert^2}{m^2_{\tilde{b}_R}}$, $\frac{\log\left(m^2_{\tilde{t}_L}/m^2_{\tilde{\nu}_\tau}\right)}{(m^2_{\tilde{t}_L}-m^2_{\tilde{\nu}_\tau})}(\lambda'_{33i}\cdot\lambda'_{32i})\lvert\lambda'_{23i}\rvert^2$, $\frac{\log\left(m^2_{\tilde{b}_R}/m^2_{\tilde{\tau}_R}\right)}{(m^2_{\tilde{b}_R}-m^2_{\tilde{\tau}_R})}\lambda'_{i33}\lambda'_{i'23}\lambda_{2i3}\lambda_{2i'3}$, $\frac{1}{m^2_{\tilde{\nu}_\tau}}\lambda'_{33i}\lambda'_{3i2}\lambda_{32j}\lambda_{3j2}$
$(g-2)_\mu$	$\lambda_{32k}, \lambda_{3k2}, \lambda_{k23}$ $\lambda'_{233}, \lambda'_{223}, \lambda'_{213}$, $m_{\tilde{b}_R}, m_{\tilde{\tau}_R}, m_{\tilde{\tau}_L}, m_{\tilde{\nu}_\tau}$	$\lvert\lambda_{32k}\rvert^2\frac{2}{m^2_{\tilde{\nu}_\tau}}$, $\lvert\lambda_{3k2}\rvert^2\left(\frac{2}{m^2_{\tilde{\nu}_\tau}}-\frac{1}{m^2_{\tilde{\tau}_L}}\right)$, $-\lvert\lambda_{k23}\rvert^2\frac{1}{m^2_{\tilde{\tau}_R}}$, $\frac{\lvert\lambda'_{233}\rvert^2}{m^2_{\tilde{b}_R}-m^2_t}$, $\frac{1}{m^2_{\tilde{b}_R}}(\lvert\lambda'_{213}\rvert^2+\lvert\lambda'_{223}\rvert^2)$
ANITA	$\lambda'_{123}, \lambda'_{223}, \lambda'_{233}, \lambda'_{323}, \lambda'_{333}, m_{\tilde{b}_R}, m_{\tilde{\chi}^0_1}$	$\frac{\lvert\lambda'_{ij3}\rvert^2 m^5_{\tilde{\chi}^0_1}}{m^4_{\tilde{b}_R}}$

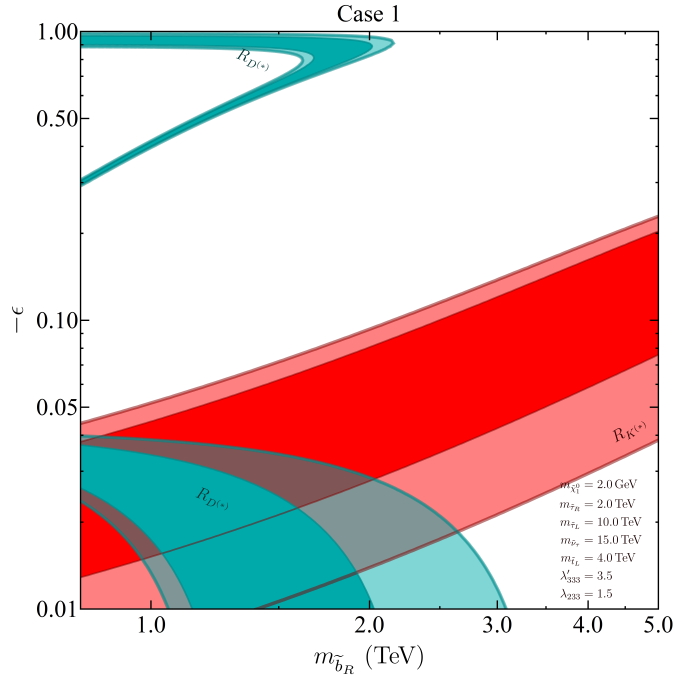
Parameter Dependence of Constraints

Constraint	Parameter dependence	Relevant terms
$B \to \tau\nu$	$\lambda'_{\ell' 33},\ \lambda'_{3j3}\ ,\ m_{\tilde{b}_R}$	$\frac{\lambda'_{\ell' 33} \cdot \lambda'_{3j3}}{m^2_{\tilde{b}_R}}$
$B \to K^{(*)} \nu\bar{\nu}$	$\lambda'_{\ell' 33},\ \lambda'_{\ell 23}\ ,\ m_{\tilde{b}_R}$	$\frac{\lambda'_{\ell' 33} \cdot \lambda'_{\ell 23}}{m^2_{\tilde{b}_R}},\ \frac{\lambda'_{\ell' 33} \cdot \lambda'_{\ell 32}}{m^2_{\tilde{b}_L}}$
$B \to \pi/\rho\, \nu\bar{\nu}$	$\lambda'_{\ell' 33},\ \lambda'_{\ell 13}\ ,\ m_{\tilde{b}_R}$	$\frac{\lambda'_{\ell' 33} \cdot \lambda'_{\ell 13}}{m^2_{\tilde{b}_R}}$
$B_s - \overline{B}_s$ mixing	$\lambda'_{i33},\ \lambda'_{i23},\ \lambda'_{i32}\ ,$ $m_{\tilde{b}_R},\ m_{\tilde{\nu}}$	$\frac{\lambda'_{i23}\lambda'_{i33}\lambda'_{j23}\lambda'_{j33}}{m^2_{\tilde{b}_R}},$ $\frac{\lambda'_{i23}\lambda'_{i32}\lambda'_{j33}\lambda'_{j33}}{m^2_{\tilde{b}_R}}\ ,$ $\frac{\lambda'_{332}\lambda'_{323}}{m^2_{\tilde{\nu}}}$
$D - \overline{D}$ mixing	$\lambda'_{323},\ m_{\tilde{b}_R},\ m_{\tilde{\tau}_R}$	$\frac{\lambda'^4_{323}}{m^2_{\tilde{b}_R}},\ \frac{\lambda'^4_{323}}{m^2_{\tilde{\tau}_R}}$
$D^0 \to \mu^+\mu^-$	$\lambda'_{2j3},\ m_{\tilde{b}_R}$	$\frac{\lambda'_{2j3}\lambda'_{2j'3}}{m^2_{\tilde{b}_R}}$
$\tau \to \ell\nu\bar{\nu}$	$\lambda_{323},\ \lambda'_{333},\ m_{\tilde{\tau}_R},\ m_{\tilde{b}_R}$	$\frac{\lambda^2_{323}}{m^2_{\tilde{\tau}_R}},\ \frac{\lambda'^2_{333}}{m^2_{\tilde{b}_R}}$
$Z \to \ell\bar{\ell}'$	$\lambda'_{333},\ m_{\tilde{b}_R}$	$\frac{\lambda'^2_{333}}{m^2_{\tilde{b}_R}}$

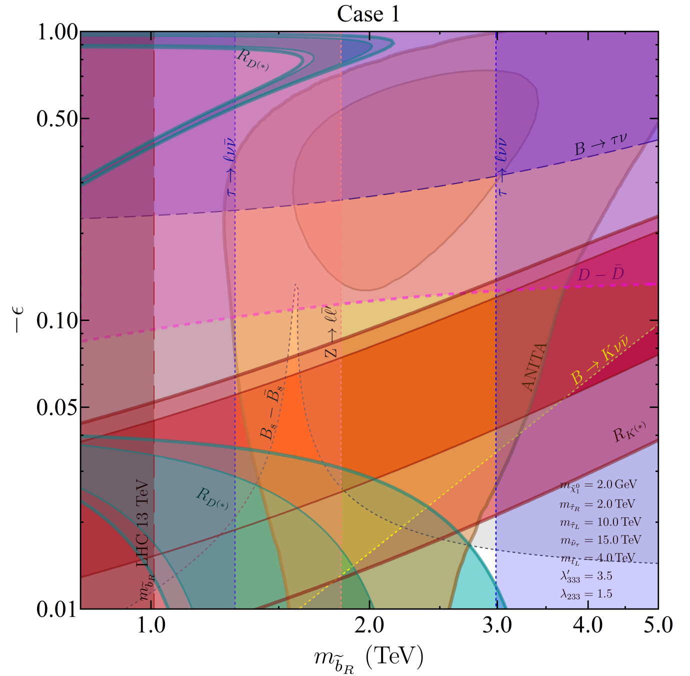
Case 1 (CKM-Like)



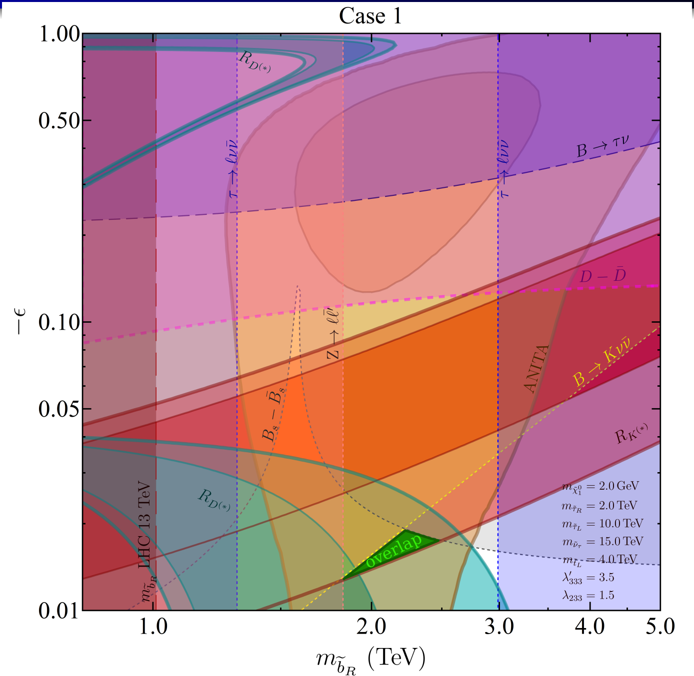
Case 1 (CKM-Like)



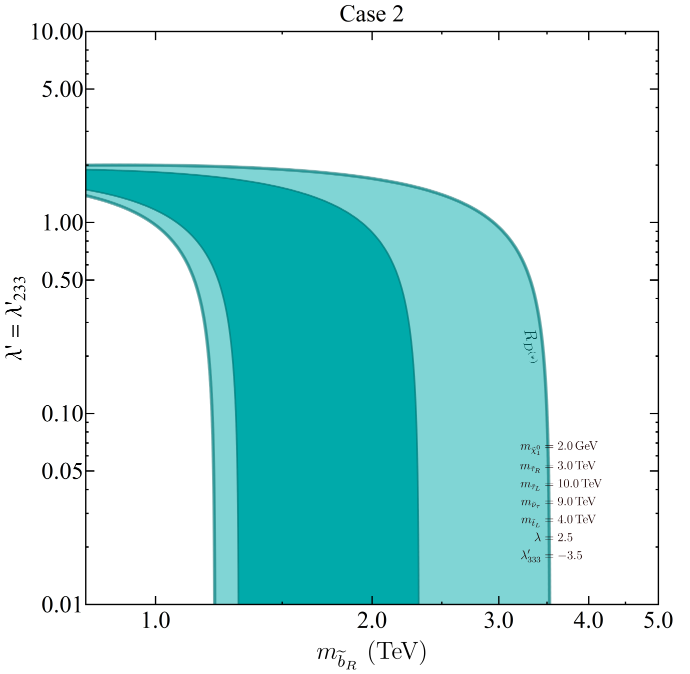
Case 1 (CKM-Like)



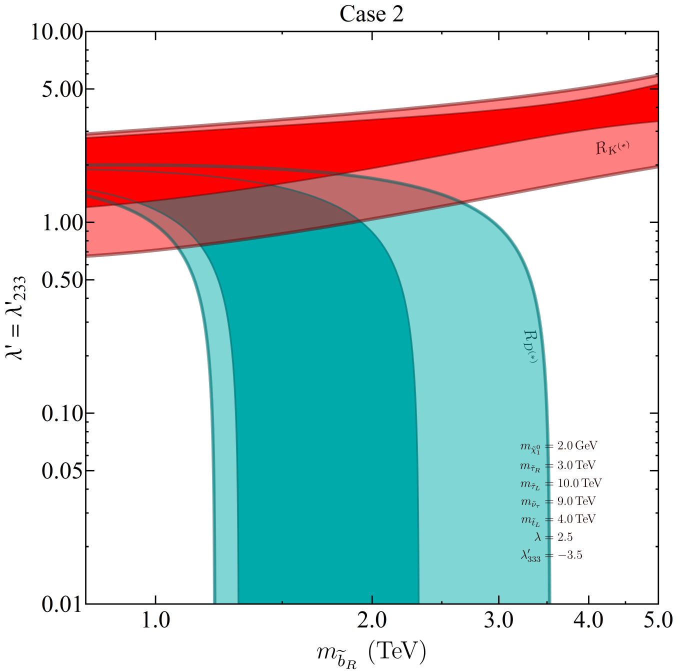
Case 1 (CKM-Like)



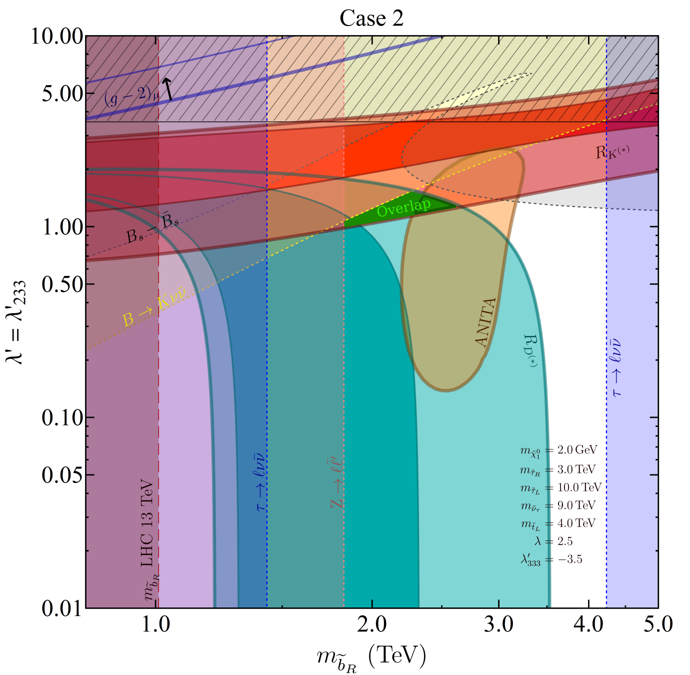
Case 2 (Flavor Symmetry)



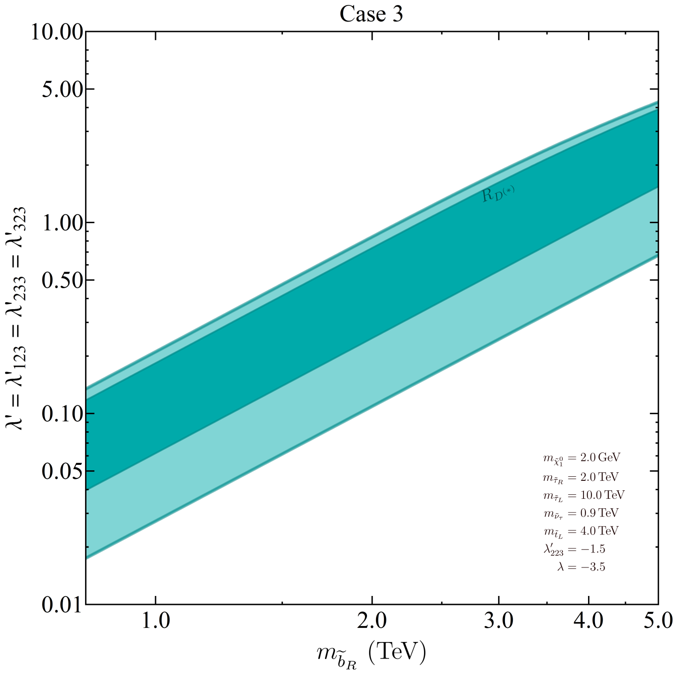
Case 2 (Flavor Symmetry)



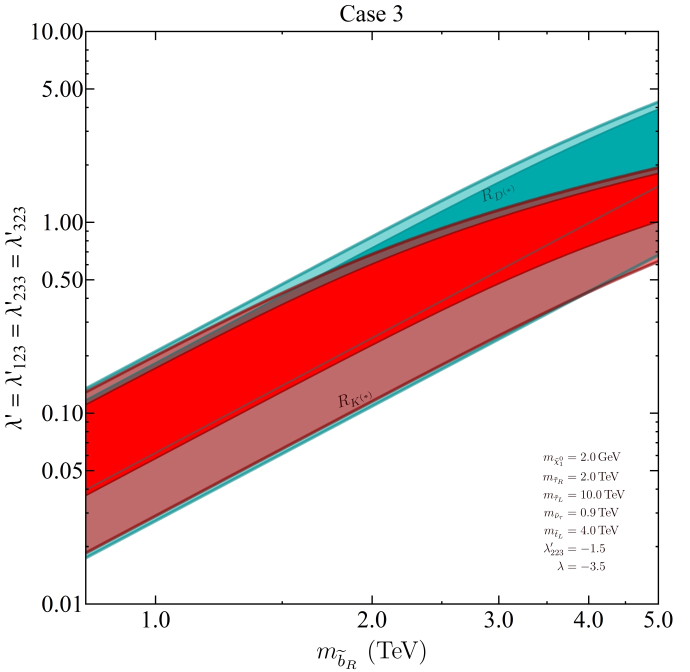
Case 2 (Flavor Symmetry)



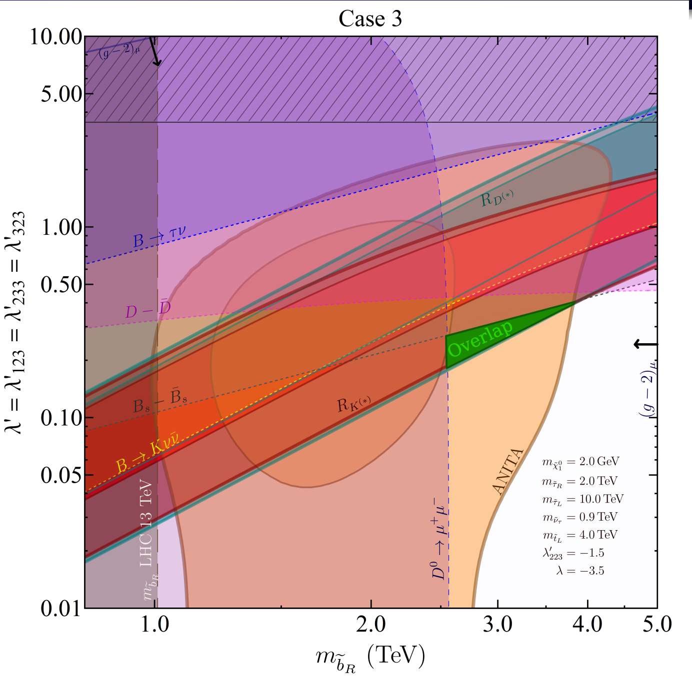
Case 3 (No Symmetry)



Case 3 (No Symmetry)

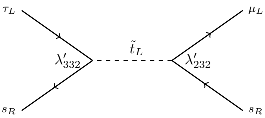


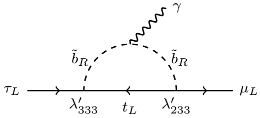
Case 3 (No Symmetry)

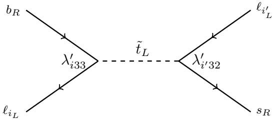


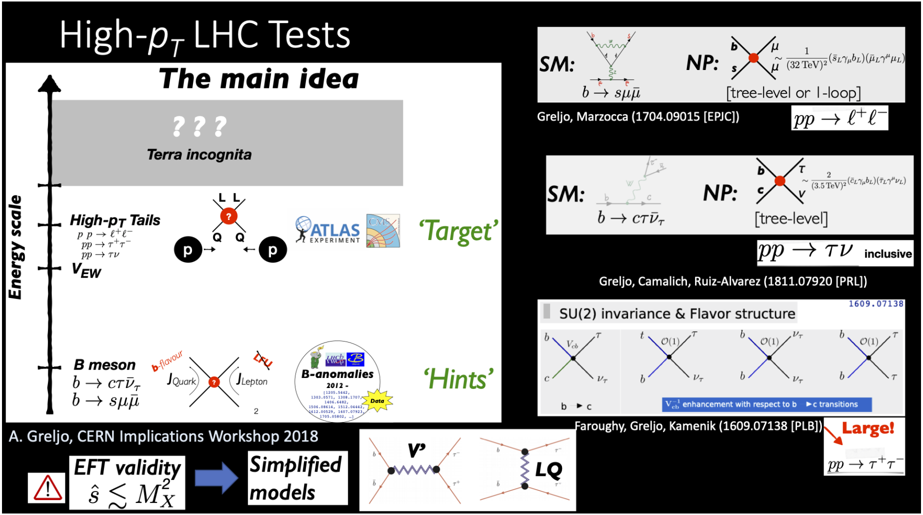
LFV Predictions

Flavor-violating decay mode	λ,λ' dependence	RPV3 Prediction Case 1	RPV3 Prediction Case 2	RPV3 Prediction Case 3	Current experimental bound/measurement
$\tau\to\mu\phi$	$\lambda'_{332}\lambda'_{232}$, $\lambda_{323}\lambda'_{322}$	1.9×10^{-15}	3.8×10^{-10}	2.6×10^{-12}	$<8.4\times10^{-8}$
$\tau\to\mu KK$	$\lambda'_{332}\lambda'_{232}$, $\lambda_{323}\lambda'_{322}$	1.2×10^{-17}	2.4×10^{-12}	2.9×10^{-13}	$<4.4\times10^{-8}$
$\tau\to\mu K^0_s$	$\lambda'_{332}\lambda'_{231}$, $\lambda'_{312}\lambda_{323}$	4.5×10^{-19}	8.7×10^{-12}	3.1×10^{-13}	$<2.3\times10^{-8}$
$\tau\to\mu\gamma$	$\lambda'_{333}\lambda'_{233}$, $\lambda_{133}\lambda_{123}$	1.3×10^{-10}	1.3×10^{-8}	2.4×10^{-10}	$<4.4\times10^{-8}$
$\tau\to\mu\mu\mu$	$\lambda_{323}\lambda_{322}$	1.7×10^{-11}	1.2×10^{-9}	1.2×10^{-11}	$<2.1\times10^{-8}$
$B_{(s)}\to K^{(*)}(\phi)\mu\tau$	$\lambda'_{333}\lambda'_{232}$, $\lambda'_{233}\lambda'_{332}$, $\lambda'_{332}\lambda_{323}$	4.1×10^{-9}	1.2×10^{-7}	2.2×10^{-10}	$<2.8\times10^{-5}$
$B_s\to\tau\mu$	$\lambda'_{333}\lambda'_{232}$, $\lambda'_{233}\lambda'_{332}$, $\lambda'_{332}\lambda_{323}$	4.4×10^{-10}	1.3×10^{-8}	2.3×10^{-11}	$<3.4\times10^{-5}$
$b\to s\tau\tau$	$\lambda'_{333}\lambda'_{332}$	3.4×10^{-7}	2.8×10^{-8}	1.3×10^{-13}	N/A
$B\to K^{(*)}\tau\tau$	$\lambda'_{333}\lambda'_{332}$	3.7×10^{-6}	4.2×10^{-8}	9.6×10^{-12}	$<2.2\times10^{-3}$
$B_s\to\tau\tau$	$\lambda'_{333}\lambda'_{332}$	3.7×10^{-8}	3.0×10^{-9}	1.4×10^{-14}	$<6.8\times10^{-3}$
$b\to s\mu\mu$	$\lambda'_{233}\lambda'_{232}$, $\lambda'_{332}\lambda_{232}$	5.9×10^{-9}	3.2×10^{-8}	8.8×10^{-9}	4.4×10^{-6}
$B_s\to\mu\mu$	$\lambda'_{233}\lambda'_{232}$, $\lambda'_{332}\lambda_{232}$	4.1×10^{-11}	6.5×10^{-11}	1.8×10^{-11}	3.0×10^{-9}









An independent test of the B-anomalies

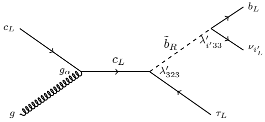
Distinct LHC Signals in RPV3

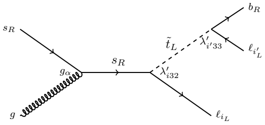
- Effective operators:

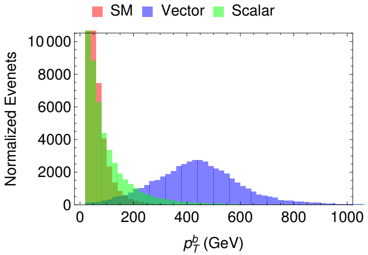
$$R_{D^{(*)}} \; : \mathcal{O}_{V_L} = (\bar{c}\gamma^\mu P_L b)(\bar{\tau}\gamma_\mu P_L \nu)$$

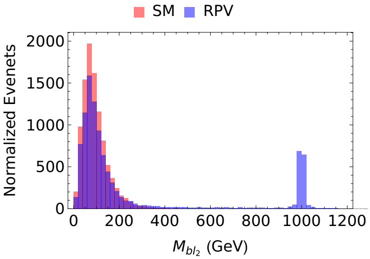
$$R_{K^{(*)}} \; : Q^{\ell}_{9(10)} = (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu(\gamma_5)\ell)$$

- Crossing symmetry: $b \to c\tau\nu$ leads to $gc \to b\tau\nu$, and $b \to s\ell\ell$ leads to $gs \to b\ell\ell$.





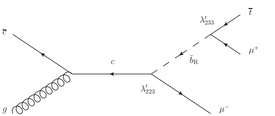


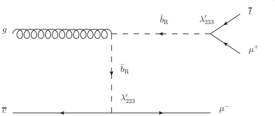


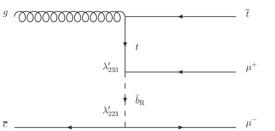
[Altmannshofer, BD, Soni (PRD '17)]

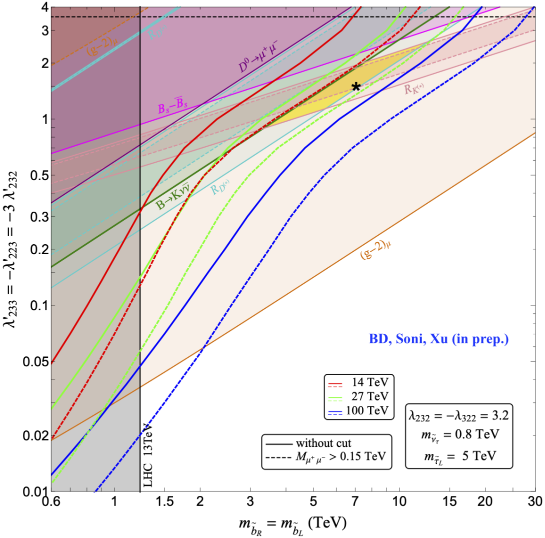
[Altmannshofer, BD, Soni, Sui (PRD '20)]

More LHC Signals

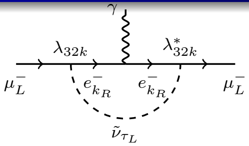


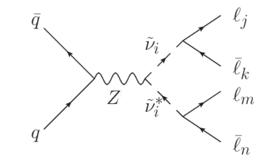


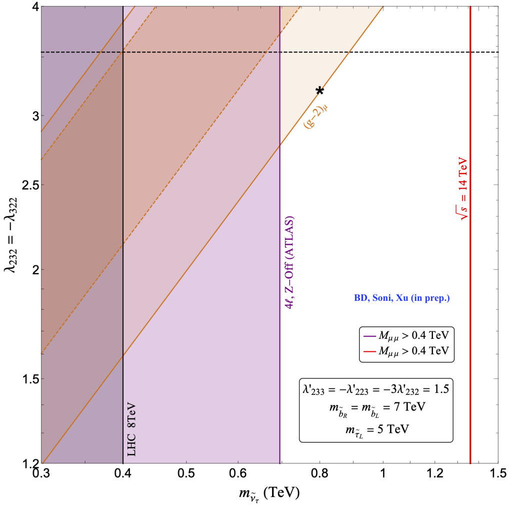




An LHC Test of Muon $g-2$







Conclusion

- (RPV) SUSY remains an attractive BSM scenario, despite null results from the LHC.
- Discussed a third-generation-centric RPV SUSY framework (RPV3), motivated by Higgs naturalness.
- Preserves gauge coupling unification.
- Provides a common solution to the B-anomalies (both $R_{D^{(*)}}$ and $R_{K^{(*)}}$) and muon $g-2$ in a single testable framework.
- Predictions for flavor-violating B-meson and tau decays could be tested at Belle II and LHCb.
- Complementary tests in the high-p_T LHC experiments.
- A direct test of muon $g-2$ at the LHC.
- **Flavor anomalies might provide the first experimental hint of SUSY?**

Conclusion

- (RPV) SUSY remains an attractive BSM scenario, despite null results from the LHC.
- Discussed a third-generation-centric RPV SUSY framework (RPV3), motivated by Higgs naturalness.
- Preserves gauge coupling unification.
- Provides a common solution to the B-anomalies (both $R_{D^{(*)}}$ and $R_{K^{(*)}}$) and muon $g-2$ in a single testable framework.
- Predictions for flavor-violating B-meson and tau decays could be tested at Belle II and LHCb.
- Complementary tests in the high-p_T LHC experiments.
- A direct test of muon $g-2$ at the LHC.
- **Flavor anomalies might provide the first experimental hint of SUSY?**

Thank You.

ANITA

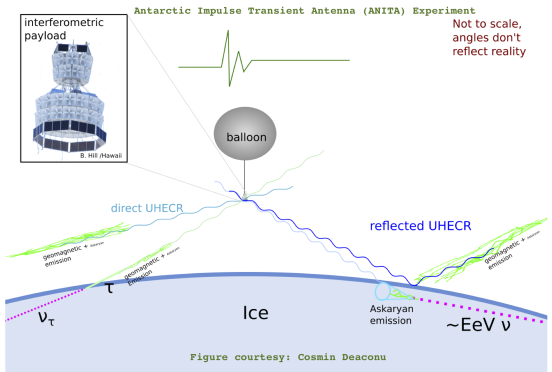


TABLE I: *ANITA-I,-III anomalous upward air showers.*
ANITA Collaboration, PRL'18

event, flight	3985267, ANITA-I	15717147, ANITA-III
date, time	2006-12-28,00:33:20UTC	2014-12-20,08:33:22.5UTC
Lat., Lon.[1]	-82.6559, 17.2842	-81.39856, 129.01626
Altitude	2.56 km	2.75 km
Ice depth	3.53 km	3.22 km
El., Az.	$-27.4 \pm 0.3°$, $159.62 \pm 0.7°$	$-35.0 \pm 0.3°$, $61.41 \pm 0.7°$
RA, Dec[2]	282.14064, +20.33043	50.78203, +38.65498
$E_{shower}^{(3)}$	0.6 ± 0.4 EeV	$0.56^{+0.3}_{-0.2}$ EeV

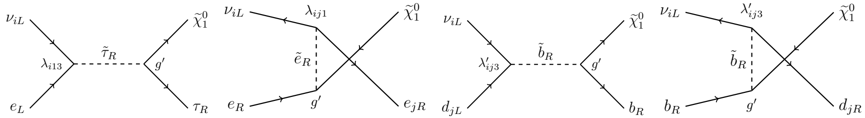
[1] Latitude, Longitude of the estimated ground position of the event.
[2] Sky coordinates projected from event arrival angles at ANITA.
[3] For upward shower initiation at or near ice surface.

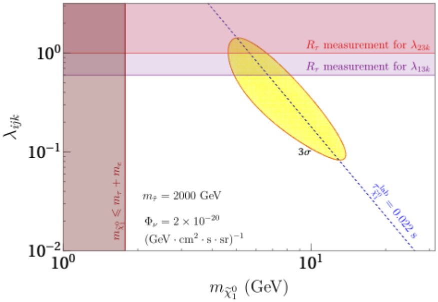
TABLE I: Preliminary list of stratospheric CR and possible anomalous CR-like events seen by ANITA-IV. 2008.05690 (PRL '21)

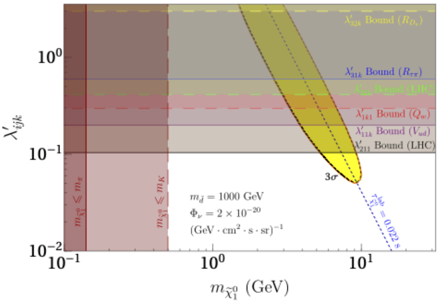
event #	mm dd hh mm ss UTC 2016	Apparent source location Lat.°,Lon.°, alt., m	elev. angle[a] degrees	horizon angle[a] degrees	azimuth degrees	Payload location Lat.°, Lon.°, alt., km	Type[c]	Energy[d] EeV
4098827	12 03 10 03 27	-75.71, 123.99, 3184	-6.17 ± 0.21	-5.92 ± 0.020	337.70	-80.157, 131.210, 38.86	NI	1.5 ± 0.7
9734523	12 05 12 55 40	-71.862, 32.61, 19000[b]	-5.64 ± 0.20	-5.95 ± 0.020	2.01	-80.9, 31.6, 39.25	AH	...
19848917	12 08 11 44 54	-80.818 , -79.87, 758	-6.71 ± 0.20	-6.06 ± 0.020	194.34	-76.66, -72.86, 38.97	NI	0.9 ± 0.5
50549772	12 16 15 03 19	-83.483, 14.73, 2572	-6.73 ± 0.20	-5.92 ± 0.020	234.08	-81.95, 47.29, 38.52	NI	0.8 ± 0.3
51293223	12 16 19 08 08	-74.800, 11.43, 18600[b]	-5.38 ± 0.24	-5.85 ± 0.020	306.45	-81.7, 39.2, 37.53	AH	...
72164985	12 22 06 28 14	-86.598, 0.35, 2589	-6.12 ± 0.10	-5.93 ± 0.020	140.03	-86.93, -104.29, 38.58	NI	3.9 ± 2.5

[a] Both the observed elevation angle and the apparent horizon here include radio refraction, which lifts the apparent horizon about 0.1°.
[b] The source elevation (in the stratosphere) and the given source position are estimates of the approximate location of EAS maximum for these direct stratospheric CR events, determined by using the average column depth to shower max for EeV CRs.
[c] AH: above-horizon, direct CR. NI: Non-inverted CR-like event, below horizon.
[d] Energy computable for below-horizon events only; above-horizon simulations are beyond our scope in this report. Errors include both statistical and systematic effects.

ANITA in RPV3







[Collins, BD, Sui (PRD '19)]