Muon g–2 and scalar leptoquark mixing*

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*I.D., Svjetlana Fajfer, and Olcyr Sumensari, arXiv:1910.03877.

Short-term scientific missions (STSM)

HOST: Department of Theoretical Physics at Jožef Stefan Institute, Ljubljana, Slovenia

DATES: January 24th, 2019 through February 5th, 2019

STSM TITLE: «Leptoquarks & (g−2)»

OUTLINE

- **PROJECT BACKGROUND**
- $(g-2)_\mu$ **VIA LEPTOQUARK MIXING**
- **CONCLUSIONS**

PROJECT BACKGROUND *

Symbol	$(SU(3), SU(2), U(1))$	Interactions	$F = 3B + L$
S_3	$(\overline{\mathbf{3}}, \mathbf{3}, 1/3)$	$\overline{Q}^C L$	-2
R_2	$(\mathbf{3}, \mathbf{2}, 7/6)$	$\overline{u}_R L$, $\overline{Q} e_R$	0
$\widetilde{R}_2$	$(\mathbf{3}, \mathbf{2}, 1/6)$	$\overline{d}_R L$	0
$\widetilde{S}_1$	$(\overline{\mathbf{3}}, \mathbf{1}, 4/3)$	$\overline{d}_R^C e_R$	-2
S_1	$(\overline{\mathbf{3}}, \mathbf{1}, 1/3)$	$\overline{Q}^C L$, $\overline{u}_R^C e_R$	-2

*I.D., S. Fajfer, A. Greljo, J.F. Kamenik, and N. Košnik, arXiv:1603.04993.

PROJECT BACKGROUND *

$$\mathcal{L}^{F=0} = \overline{q}_i \left(l^{ij} P_R + r^{ij} P_L\right) \ell_j \, S + \text{h.c.}$$

$$\mathcal{L}^{|F|=2} = \overline{q}_i^C \left(l^{ij} P_L + r^{ij} P_R\right) \ell_j \, S + \text{h.c.}$$

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PROJECT BACKGROUND

$$a_\mu = (g-2)_\mu/2 \ ^*$$

$$\delta a_\mu = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} = (2.7 \pm 0.8) \times 10^{-9}$$

*See, for example, „The anomalous magnetic moment of the muon" by Aida X. El-Khadra. Talk given at New Physics at the Low Energy Frontier, CERN Theory Institute, January 20th – February 7th, 2020.

PROJECT BACKGROUND*

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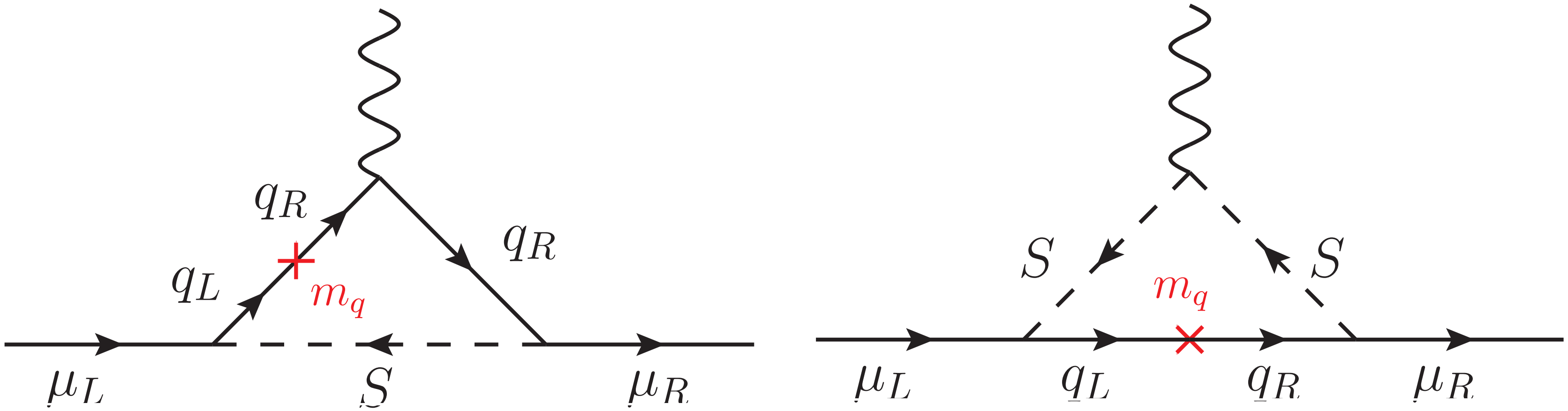


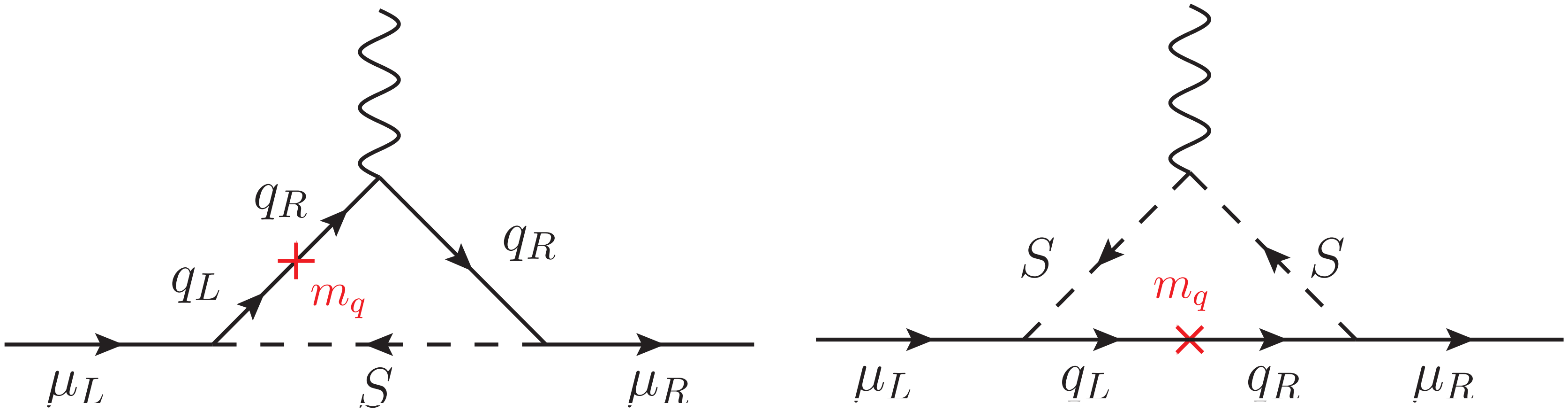
*I.D., S. Fajfer, A. Greljo, J.F. Kamenik, and N. Košnik, arXiv:1603.04993.

PROJECT BACKGROUND*

$$\delta a_\mu = -\frac{N_c m_\mu}{8\pi^2 m_S^2} \sum_q \Big[m_\mu \big(|l^{q\mu}|^2 + |r^{q\mu}|^2\big)\, \mathcal{F}_{Q_S}(x_q) + m_q\, \mathrm{Re}(r^{q\mu *}\, l^{q\mu})\, \mathcal{G}_{Q_S}(x_q) \Big]$$

$$\mathcal{L}^{F=0} = \overline{q}_i\, (l^{ij} P_R + r^{ij} P_L)\, \ell_j\, S + \mathrm{h.c.}$$

$$\mathcal{L}^{|F|=2} = \overline{q}_i^{C}\, (l^{ij} P_L + r^{ij} P_R)\, \ell_j\, S + \mathrm{h.c.}$$



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PROJECT BACKGROUND

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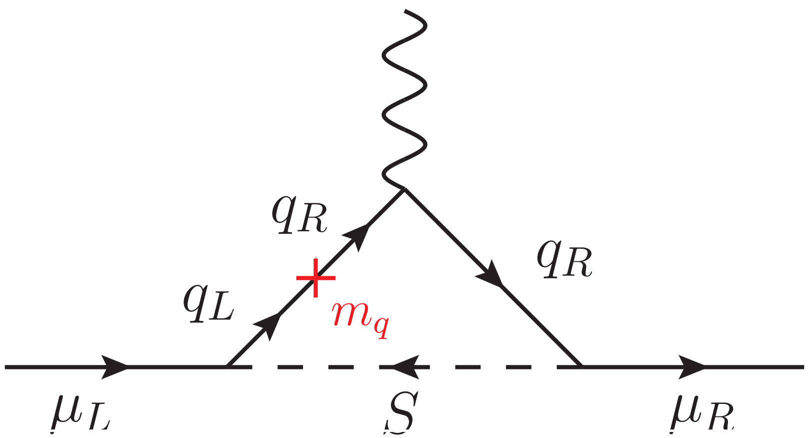
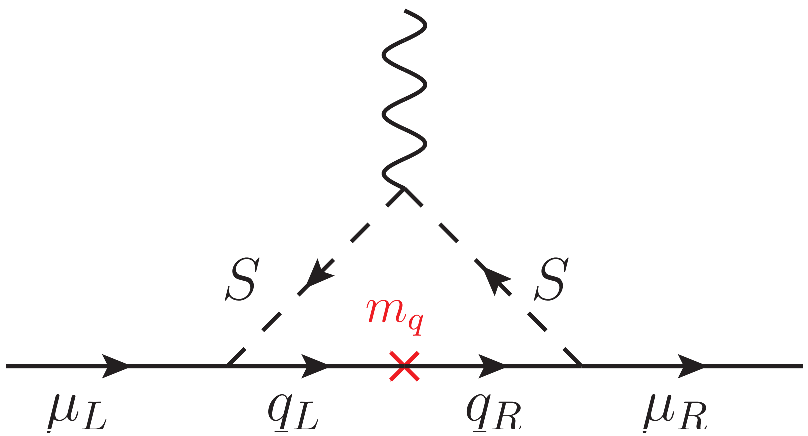
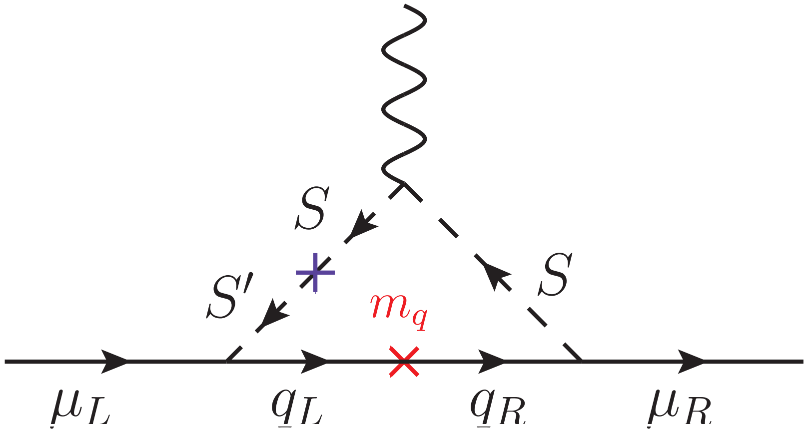
$\widetilde{S}_1$	$(\overline{\mathbf{3}}, \mathbf{1}, 4/3)$	$\overline{d}_R^C e_R$	-2	
S_1	$(\overline{\mathbf{3}}, \mathbf{1}, 1/3)$	$\overline{Q}^C L,\ \overline{u}_R^C e_R$	-2	*

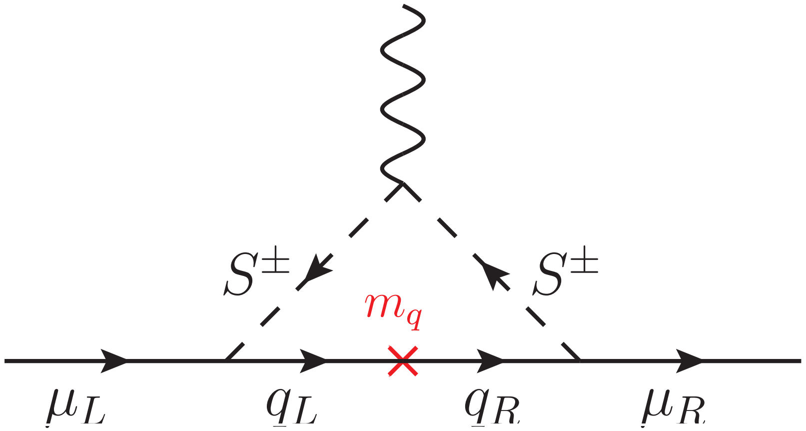




*K. Kowalska, E.M. Sessolo, and Y. Yamamoto, arXiv:1812.06851.

PROJECT BACKGROUND *





*I.D., Svjetlana Fajfer, and Olcyr Sumensari, arXiv:1910.03877.

$(g-2)_\mu$ VIA LEPTOQUARK MIXING*

LQ pairs	Mixing field(s)	$(g-2)_\mu$	ν-mass
S_1 & S_3	$H\ H$	u	–
$\widetilde{S}_1$ & S_3	$H\ H$	d	–
$\widetilde{R}_2$ & R_2	$H\ H$	d	–
$\widetilde{R}_2$ & S_1	H	–	d
$\widetilde{R}_2$ & S_3	H	–	d

$$H = (\mathbf{1}, \mathbf{2}, 1/2)$$

*I.D., Svjetlana Fajfer, and Olcyr Sumensari, arXiv:1910.03877.

*I.D., Svjetlana Fajfer, and Nejc Košnik, arXiv:1701.08322.

$(g-2)\mu$ VIA LEPTOQUARK MIXING*

$$\mathcal{M}^2 = \begin{pmatrix} m^2_{S_a} & \Omega \\ \Omega & m^2_{S_b} \end{pmatrix}$$

$$\begin{pmatrix} S_-^{(Q)} \\ S_+^{(Q)} \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} S_a^{(Q)} \\ S_b^{(Q)} \end{pmatrix}$$

$$\tan 2\theta = \frac{2\,\Omega}{m^2_{S_a} - m^2_{S_b}}$$

$$\boxed{m_{S_a} = m_{S_b} \equiv m_S \qquad \theta = \pi/4 \qquad \delta m_S^{(Q)} = m_{S_+^{(Q)}} - m_S \approx m_S - m_{S_-^{(Q)}}}$$

*I.D., Svjetlana Fajfer, and Olcyr Sumensari, arXiv:1910.03877.

(g–2)μ VIA LEPTOQUARK MIXING*

$$\boxed{S_1 \;\&\; S_3}$$

$$\mathcal{L}_{\text{mix}}^{S_1\,\&\,S_3} = \xi\, H^\dagger(\vec{\tau}\cdot\vec{S_3})HS_1^* + \text{h.c.}$$

$$\Omega = -\xi\, v^2/2$$

$$m_{S_\pm^{(1/3)}},\, m_{S_3} \equiv m_{S_3^{(4/3)}} = m_{S_3^{(-2/3)}}$$

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$(g-2)\mu$ VIA LEPTOQUARK MIXING*

$$\boxed{S_1 \;\&\; S_3}$$

$$m_{S_1} = m_{S_3} \equiv m_S$$

$$\delta m_S^{(1/3)} \equiv m_S - m_{S_-^{(1/3)}} \approx m_{S_+^{(1/3)}} - m_S > 0$$

$$\Delta T_{S_1\,\&\,S_3} = \frac{N_c}{3\pi s_W^2}\left(\frac{\delta m_S^{(1/3)}}{m_W}\right)^2\left[1 + \mathcal{O}\left(\frac{\delta m_S^{(1/3)}}{m_S}\right)^2\right]$$

$$\left[\delta m_S^{(1/3)}\right]_{S_1\,\&\,S_3} \lesssim 40\,\mathrm{GeV}$$

$$\boxed{\Delta T = 0.05(12)}\;^{*}$$

*I.D., Svjetlana Fajfer, and Olcyr Sumensari, arXiv:1910.03877.

*M. Baak et al, arXiv:1209.2716.

(g−2)μ VIA LEPTOQUARK MIXING*

$$S_1 \ \&\ S_3$$

$$\mathcal{L}_{S_1} = y_R^{ij}\, \overline{u}_{Ri}^C e_{Rj}\, S_1 + \text{h.c.}$$

$$\mathcal{L}_{S_3} = y_L^{ij}\, \overline{Q}_i^C\, i\tau_2(\vec{\tau}\cdot\vec{S}_3)L_j + \text{h.c.}$$

$$\mathcal{L}_{S_1\,\&\,S_3} = y_R^{ij}\, \bar{u}_{Ri}^C e_{Rj}\, S_1^{(1/3)} - y_L^{ij}\bar{d}_{Li}^C \nu_{Lj}\, S_3^{(1/3)} - \sqrt{2}y_L^{ij}\bar{d}_{Li}^C e_{Lj}\, S_3^{(4/3)} + \sqrt{2}\,(V^* y_L)^{ij}\, \bar{u}_{Li}^C \nu_{Lj}\, S_3^{(-2/3)} - (V^* y_L)^{ij}\, \bar{u}_{Li}^C e_{Lj}\, S_3^{(1/3)} + \text{h.c.}$$

$$\{m_S, \delta m_S^{(1/3)}, y_L^{b\mu}, y_R^{t\mu}\}$$

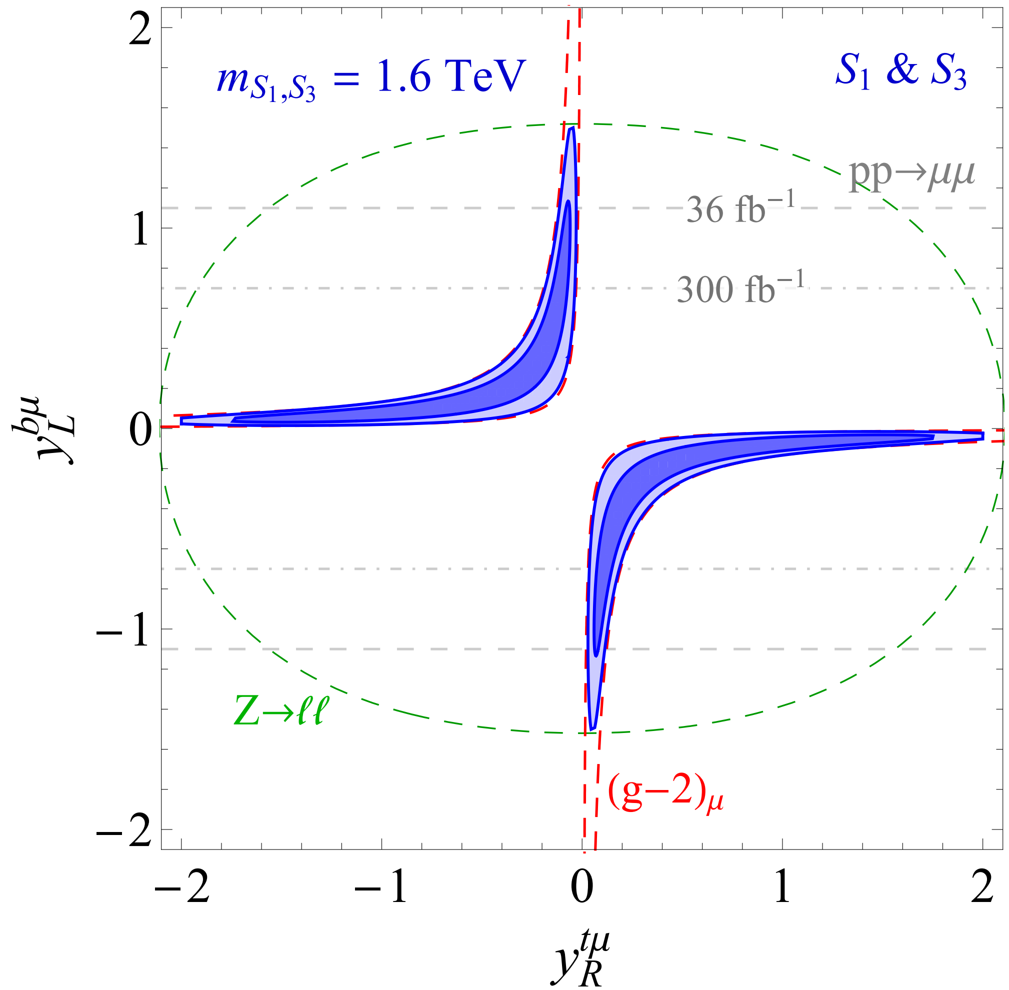
$$\theta = \pi/4 \qquad\qquad m_{S_1} = m_{S_3} \equiv m_S = 1.6\,\text{TeV}$$

$$\delta m_S^{(1/3)} \equiv m_S - m_{S_-^{(1/3)}} \approx m_{S_+^{(1/3)}} - m_S > 0$$

*I.D., Svjetlana Fajfer, and Olcyr Sumensari, arXiv:1910.03877.

NUMERICAL ANALYSIS

S_1 & S_3



(g–2)μ VIA LEPTOQUARK MIXING*

$$\boxed{\widetilde{S}_1 \ \& \ S_3}$$

$$\mathcal{L}_{\rm mix}^{\widetilde{S}_1 \ \& \ S_3} = \xi\, H^T i\tau_2 (\vec{\tau}\cdot\vec{S_3}) H \widetilde{S}_1^* + {\rm h.c.}$$

$$\Omega = -\xi\, v^2/2$$

$$m_{S_\pm^{(4/3)}},\, m_{S_3} = m_{S_3^{(1/3)}} = m_{S_3^{(-2/3)}}$$

$$m_{S_3} = m_{\widetilde{S}_1} \equiv m_S$$

$$\delta m_S^{(4/3)} \equiv m_S - m_{S_-} \approx m_{S_+} - m_S > 0$$

$$\left[\delta m_S^{(4/3)}\right]_{\widetilde{S}_1 \ \& \ S_3} \lesssim 50\,{\rm GeV}$$

*I.D., Svjetlana Fajfer, and Olcyr Sumensari, arXiv:1910.03877.

$(g-2)_\mu$ VIA LEPTOQUARK MIXING*

$$\boxed{\widetilde{S}_1 \;\&\; S_3}$$

$$\mathcal{L}_{\widetilde{S}_1} = y_R^{ij}\, \bar{d}_{Ri}^C\, e_{Rj}\, \widetilde{S}_1 + \text{h.c.}$$

$$\mathcal{L}_{S_3} = y_L^{ij}\, \bar{Q}_i^C\, i\tau_2 (\vec{\tau}\cdot\vec{S}_3) L_j + \text{h.c.}$$

$$\begin{aligned}\mathcal{L}_{\widetilde{S}_1\,\&\,S_3} = {} & y_R^{ij}\, \bar{d}_{Ri}^C\, e_{Rj}\, \widetilde{S}_1^{(4/3)} - y_L^{ij}\, \bar{d}_{Li}^C \nu_{Lj}\, S_3^{(1/3)} - \sqrt{2} y_L^{ij}\, \bar{d}_{Li}^C e_{Lj}\, S_3^{(4/3)} \\ & + \sqrt{2}\,(V^* y_L)^{ij}\, \bar{u}_{Li}^C \nu_{Lj}\, S_3^{(-2/3)} - (V^* y_L)^{ij}\, \bar{u}_{Li}^C e_{Lj}\, S_3^{(1/3)} + \text{h.c.}\end{aligned}$$

$$\{m_S, \delta m_S^{(4/3)}, y_L^{b\mu}, y_R^{b\mu}\}$$

$$\theta = \pi/4 \qquad\qquad m_{S_3} = m_{\widetilde{S}_1} \equiv m_S = 1.6\,\text{TeV}$$

$$\delta m_S^{(4/3)} \equiv m_S - m_{S_-} \approx m_{S_+} - m_S > 0$$

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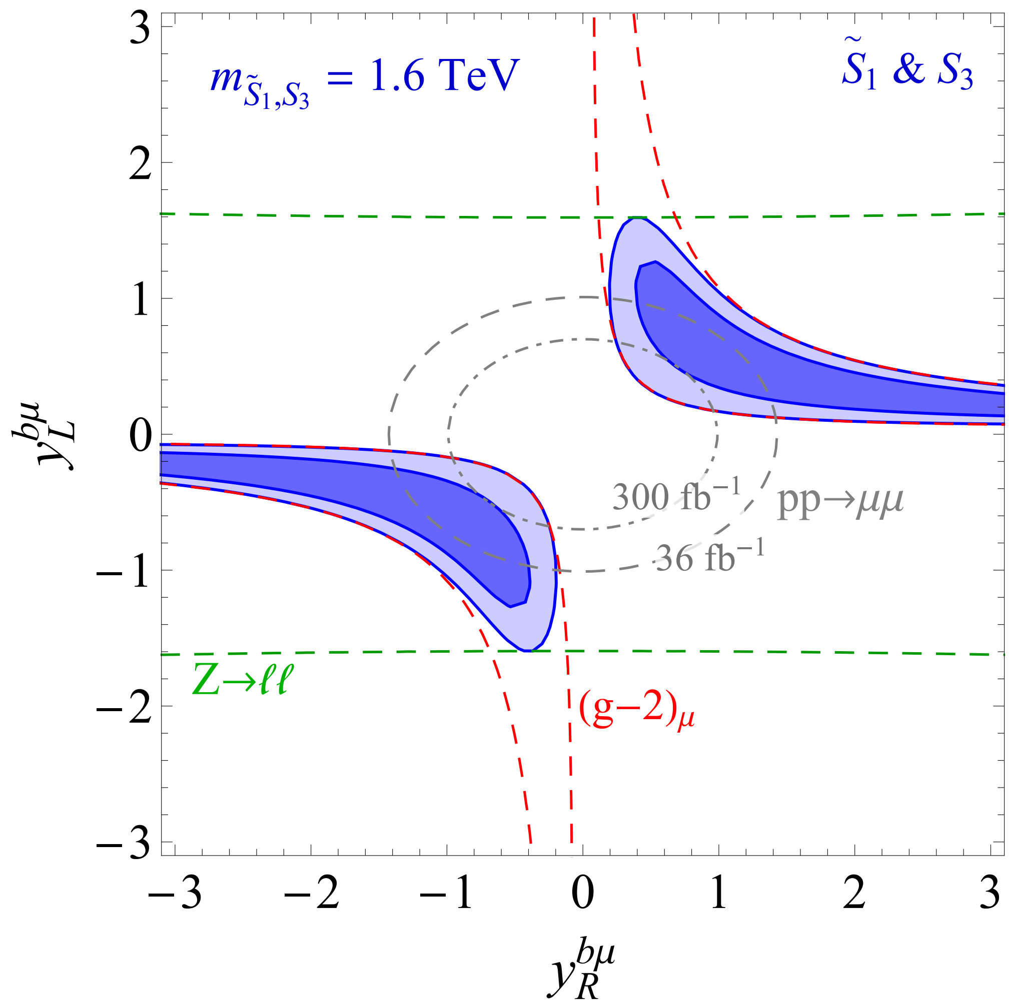

(g−2)μ VIA LEPTOQUARK MIXING*

$$\boxed{\widetilde{R}_2 \,\&\, R_2}$$

$$\mathcal{L}_{\text{mix}}^{\widetilde{R}_2 \,\&\, R_2} = -\xi \left(R_2^\dagger H\right)\left(\widetilde{R}_2^T i\tau_2 H\right) + \text{h.c.}$$

$$\Omega = -\xi\, v^2/2$$

$$m_{S_\pm^{(2/3)}},\; m_{\widetilde{R}_2} = m_{\widetilde{R}_2^{(-1/3)}},\; m_{R_2} = m_{R_2^{(5/3)}}$$

$$m_{R_2} = m_{\widetilde{R}_2} \equiv m_S$$

$$\delta m_S^{(2/3)} \equiv m_S - m_{S_-^{(2/3)}} \approx m_{S_+^{(2/3)}} - m_S$$

$$\left[\delta m_S^{(2/3)}\right]_{\widetilde{R}_2 \,\&\, R_2} \lesssim 50\,\text{GeV}$$

*I.D., Svjetlana Fajfer, and Olcyr Sumensari, arXiv:1910.03877.

(g–2)μ VIA LEPTOQUARK MIXING*

$$\widetilde{S}_1 \ \&\ S_3$$

$$\mathcal{L}_{\widetilde{R}_2} = -y_L^{ij}\,\overline{d}_{Ri}\widetilde{R}_2 i\tau_2 L_j + \text{h.c.}$$

$$\mathcal{L}_{R_2} = y_R^{ij}\,\overline{Q}_i e_{Rj} R_2 + \text{h.c.}$$

$$\begin{aligned}\mathcal{L}_{\widetilde{R}_2\,\&\,R_2} = &- y_L^{ij}\bar{d}_{Ri}e_{Lj}\widetilde{R}_2^{(2/3)} + y_L^{ij}\bar{d}_{Ri}\nu_{Lj}\widetilde{R}_2^{(-1/3)} \\ &+ (Vy_R)^{ij}\bar{u}_{Li}e_{Rj}R_2^{(5/3)} + y_R^{ij}\bar{d}_{Li}e_{Rj}R_2^{(2/3)} + \text{h.c.}\end{aligned}$$

$$\{m_S, \delta m_S^{(2/3)}, y_L^{b\mu}, y_R^{b\mu}\}$$

$$\theta = \pi/4 \qquad\qquad m_{\widetilde{R}_2} = m_{R_2} \equiv m_S = 1.6\ \text{TeV}$$

$$\delta m_S^{(2/3)} \equiv m_S - m_{S_-} \approx m_{S_+} - m_S > 0$$

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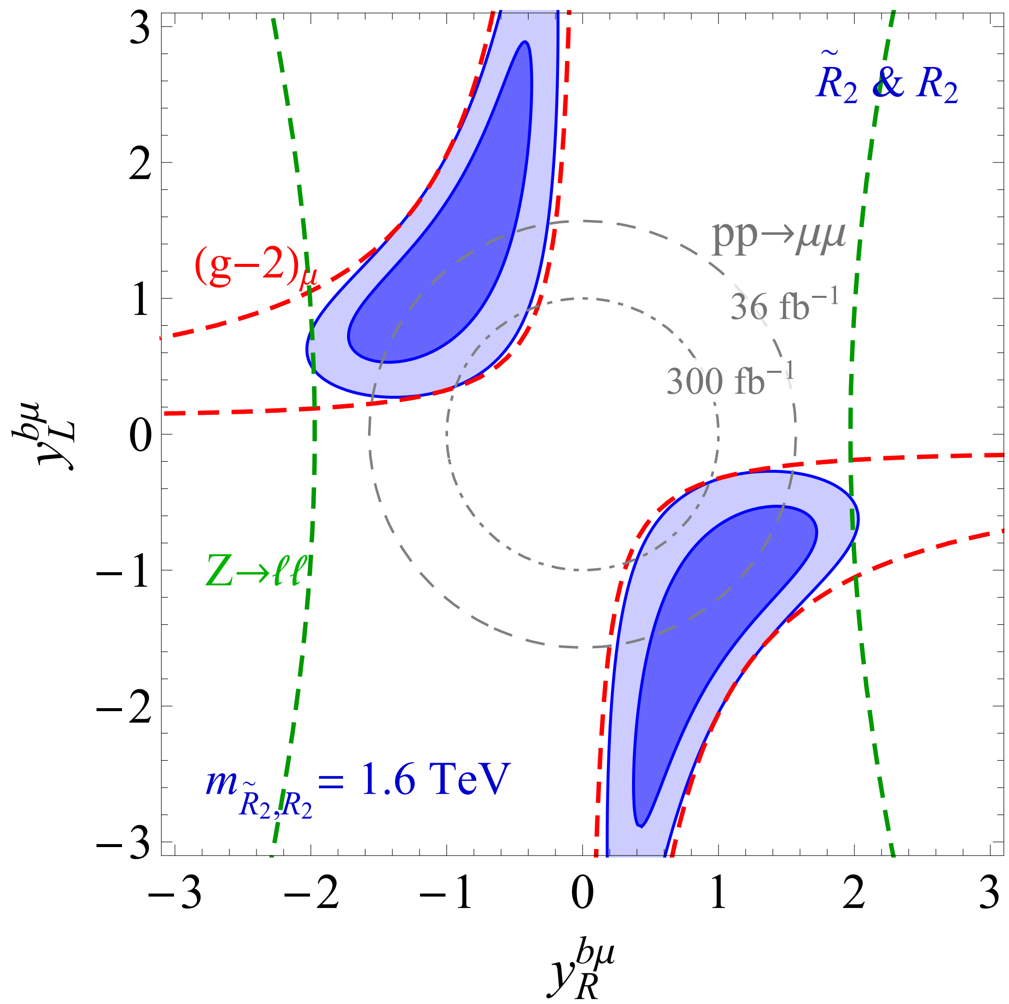
NUMERICAL ANALYSIS



CONCLUSIONS

There are three scenarios where the one-loop contributions towards the anomalous magnetic moment of muon are induced through the mixing of two scalar LQs of the same electric charge Q via the interactions with the SM Higgs field. The LQ pairs in question need to couple to muons and quarks of opposite chiralities in order to produce chirality-enhanced contributions. The three LQ pairs that satisfy these criteria are S_1 & S_3, $\widetilde{S}_1$ & S_3, and $\widetilde{R}_2$ & R_2, where the two states that mix have the electric charges $Q = 1/3$, $Q = 4/3$, and $Q = 2/3$, respectively.

The S_1 & S_3 scenario is viable for the top quark induced loops whereas the $\widetilde{S}_1$ & S_3, and $\widetilde{R}_2$ & R_2 scenarios are viable when the quark in the loop is the bottom quark.

THANK YOU

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COMPUTATIONAL DETAILS*

$$\mathcal{L}^{F=0} = \overline{q}_i\,(l^{ij} P_R + r^{ij} P_L)\,\ell_j\, S + \text{h.c.}$$

$$\mathcal{L}^{|F|=2} = \overline{q}_i^C\,(l^{ij} P_L + r^{ij} P_R)\,\ell_j\, S + \text{h.c.}$$

$$\delta a_\mu = -\frac{N_c m_\mu}{8\pi^2 m_S^2} \sum_q \Big[m_\mu (|l^{q\mu}|^2 + |r^{q\mu}|^2)\,\mathcal{F}_{Q_S}(x_q) + m_q\,\mathrm{Re}(r^{q\mu *}\, l^{q\mu})\,\mathcal{G}_{Q_S}(x_q) \Big]$$

$$\mathcal{F}_{Q_S}(x) = Q_S\, f_S(x) - f_F(x)$$

$$\mathcal{G}_{Q_S}(x) = Q_S\, g_S(x) - g_F(x)$$

$$f_S(x) = \frac{x+1}{4(1-x)^2} + \frac{x \log x}{2(1-x)^3} \qquad g_S(x) = \frac{1}{x-1} - \frac{\log x}{(x-1)^2}$$

$$f_F(x) = \frac{x^2-5x-2}{12(x-1)^3} + \frac{x \log x}{2(x-1)^4} \qquad g_F(x) = \frac{x-3}{2(x-1)^2} + \frac{\log x}{(x-1)^3}$$

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