

# 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

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

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



# PROJECT BACKGROUND \*

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

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

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# PROJECT BACKGROUND

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

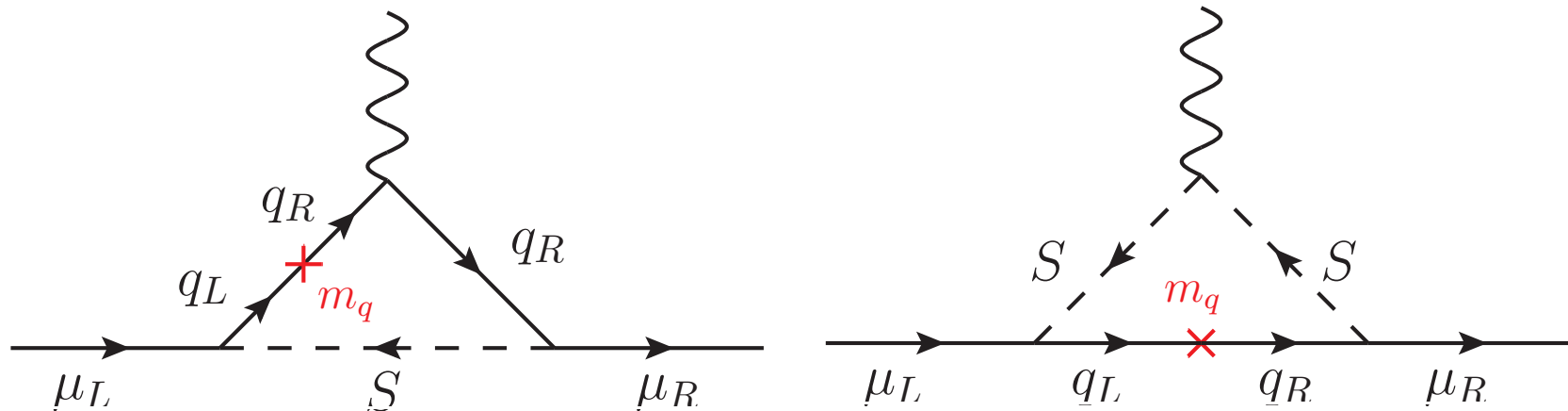
$$\delta a_{\mu} = a_{\mu}^{\text{exp}} - a_{\mu}^{\text{SM}} = (2.7 \pm 0.8) \times 10^{-9}$$

\*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 20<sup>th</sup> – February 7<sup>th</sup>, 2020.

# PROJECT BACKGROUND\*

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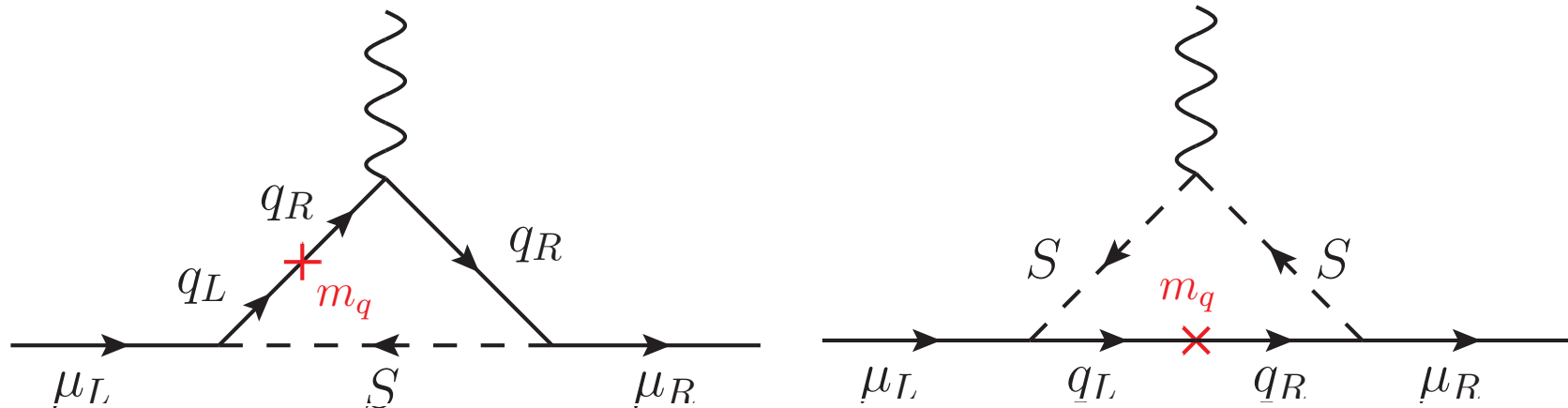
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# PROJECT BACKGROUND \*

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

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

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



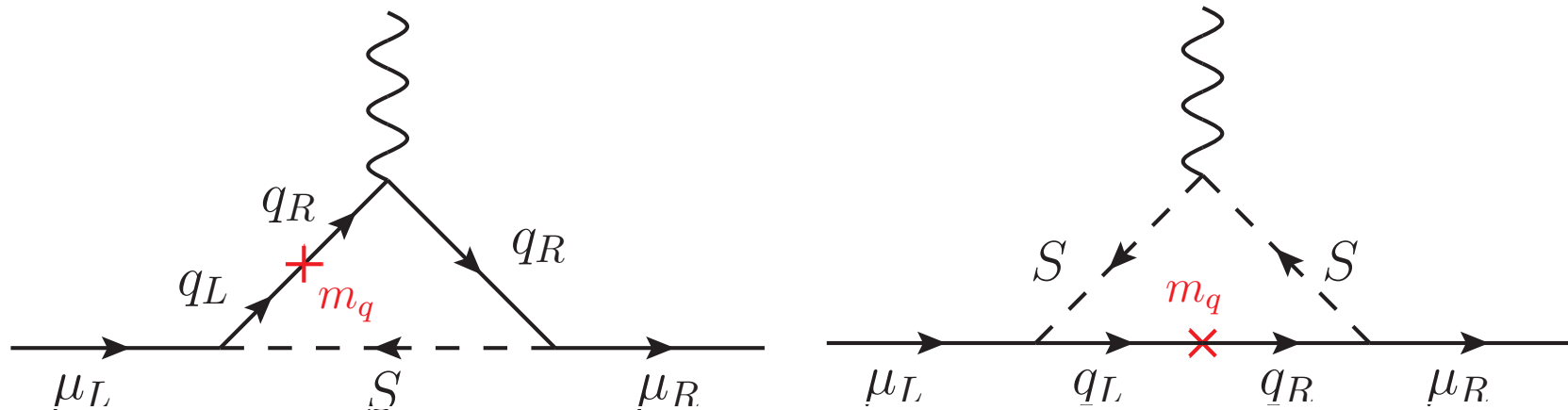
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# PROJECT BACKGROUND

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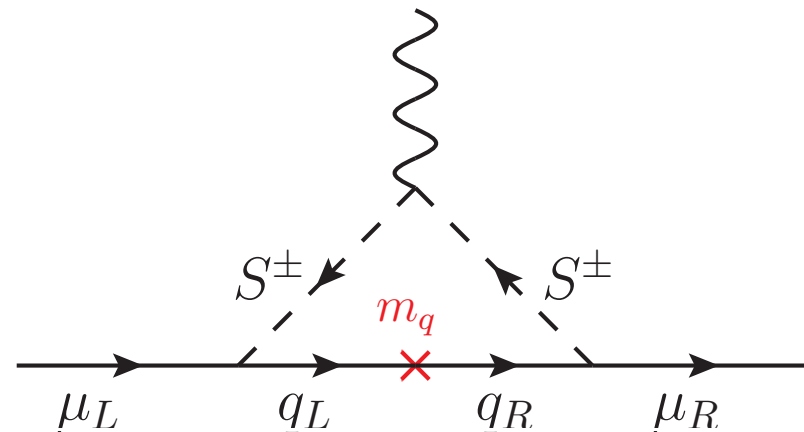
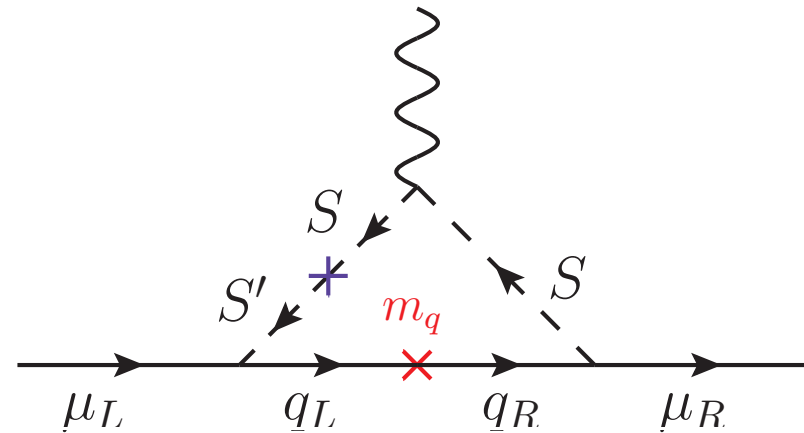
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\*K. Kowalska, E.M. Sessolo, and Y. Yamamoto, arXiv:1812.06851.

# PROJECT BACKGROUND\*



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

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

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

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

\*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\*

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

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

$$\tan 2\theta = \frac{2\Omega}{m_{S_a}^2 - m_{S_b}^2}$$

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

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



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

$S_1$  &  $S_3$

$$\mathcal{L}_{\text{mix}}^{S_1 \& S_3} = \xi H^\dagger (\vec{\tau} \cdot \vec{S}_3) H S_1^* + \text{h.c.}$$

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

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

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

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

$S_1$  &  $S_3$

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

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

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

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

$$\Delta T = 0.05(12) *$$

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

\*M. Baak et al, arXiv:1209.2716.

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

$S_1$  &  $S_3$

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

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

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

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

$$\theta = \pi/4$$

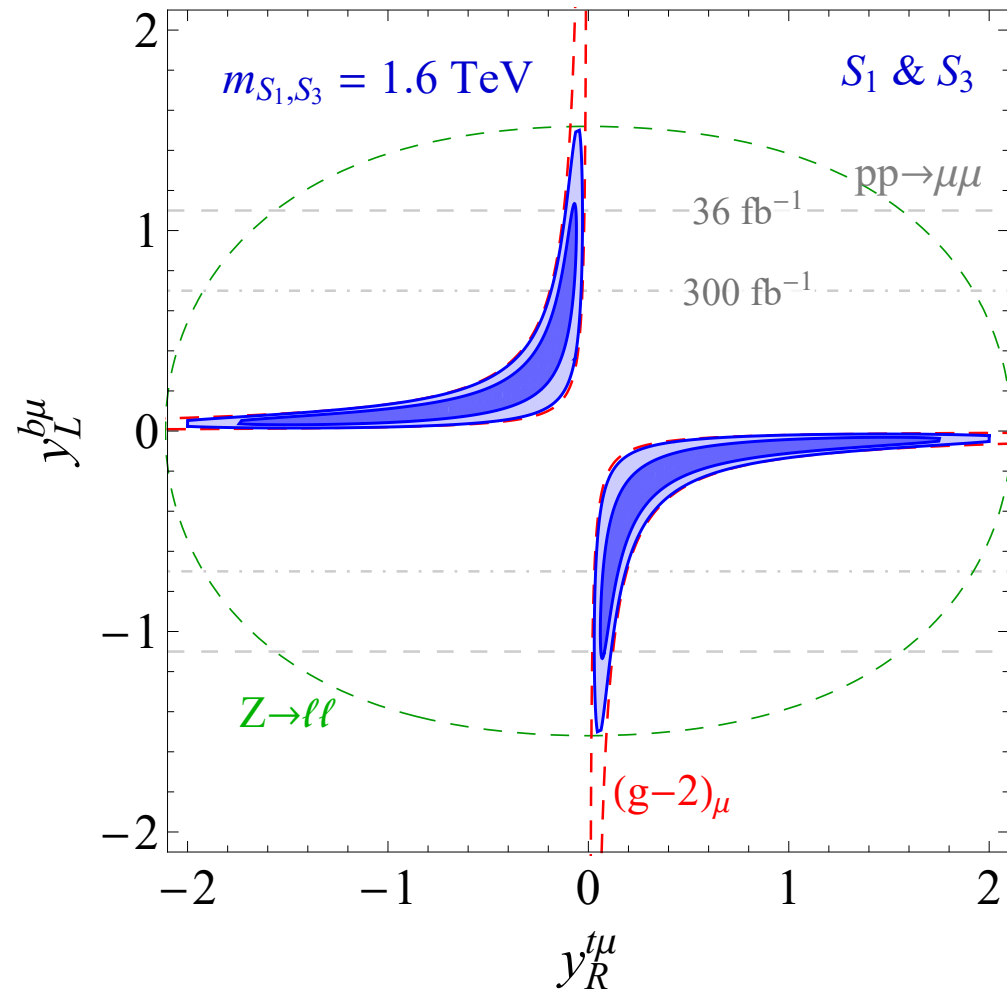
$$m_{S_1} = m_{S_3} \equiv m_S = 1.6 \text{ TeV}$$

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

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

# NUMERICAL ANALYSIS

$S_1$  &  $S_3$



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

$$\tilde{S}_1 \text{ \& } S_3$$

$$\mathcal{L}_{\text{mix}}^{\tilde{S}_1 \text{ \& } S_3} = \xi H^T i\tau_2 (\vec{\tau} \cdot \vec{S}_3) H \tilde{S}_1^* + \text{h.c.}$$

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

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

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

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

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

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

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

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

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

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

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

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

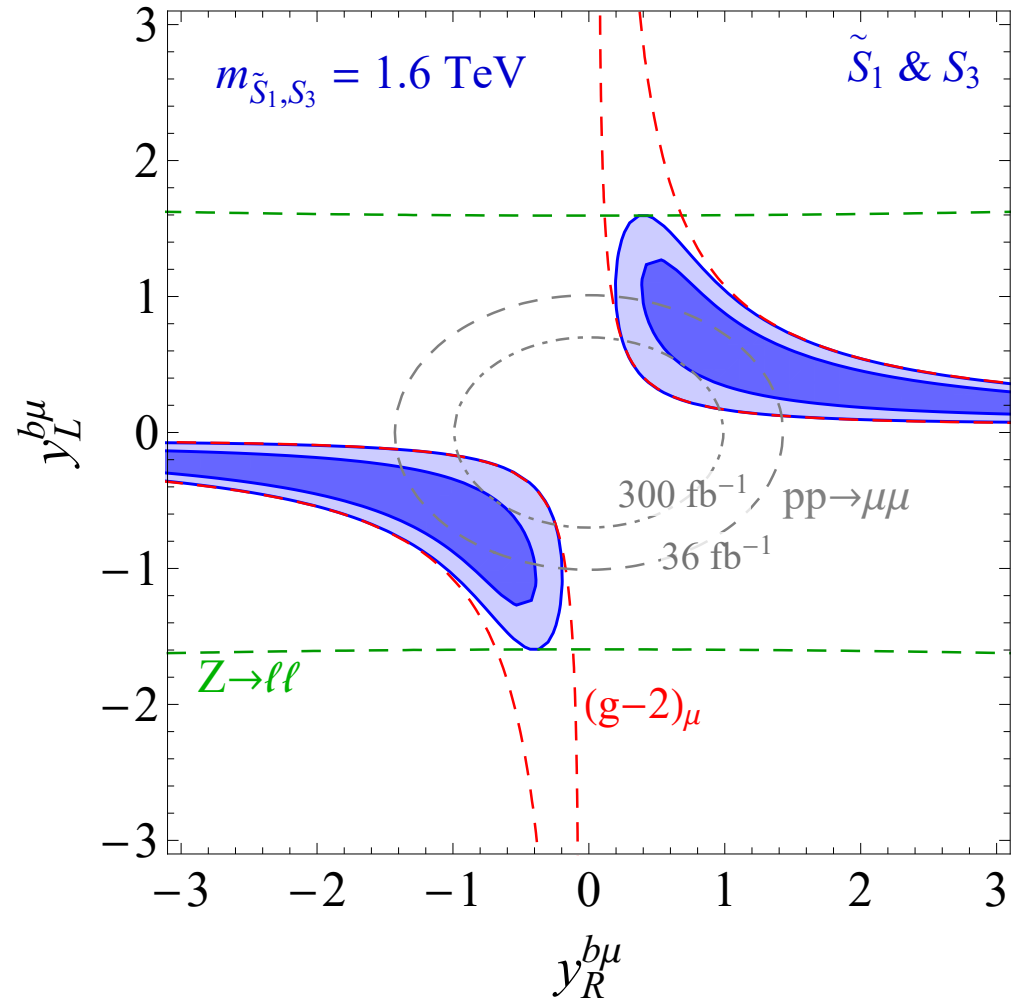
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$$m_{S_3} = m_{\tilde{S}_1} \equiv m_S = 1.6 \text{ TeV}$$

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

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

# NUMERICAL ANALYSIS



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

$$\tilde{R}_2 \text{ \& } R_2$$

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

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

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

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

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

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

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



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

$$\tilde{R}_2 \text{ \& } R_2$$

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

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

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

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

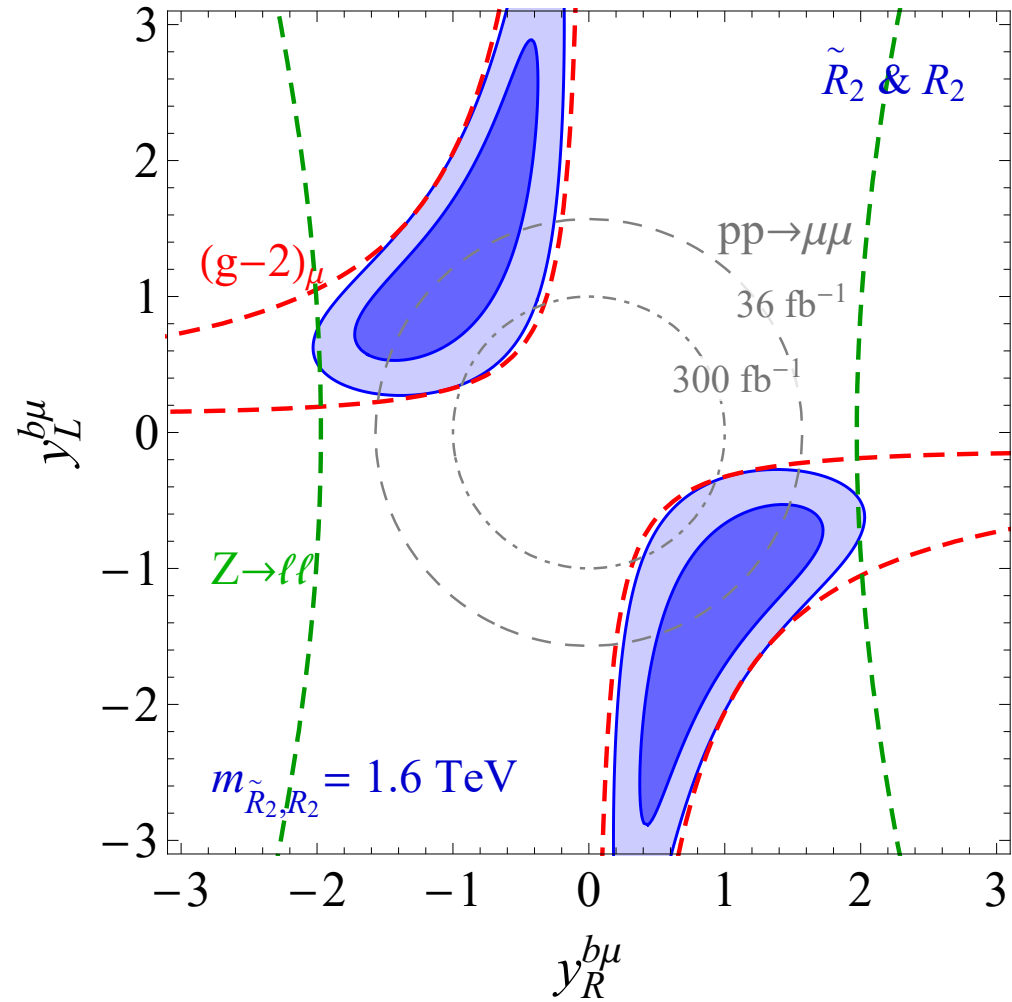
$$\theta = \pi/4$$

$$m_{\tilde{R}_2} = m_{R_2} \equiv m_S = 1.6 \text{ TeV}$$

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

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

# 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  $S_1$  &  $S_3$ ,  $\tilde{S}_1$  &  $S_3$ , and  $\tilde{R}_2$  &  $R_2$ , 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  $\tilde{S}_1$  &  $S_3$ , and  $\tilde{R}_2$  &  $R_2$  scenarios are viable when the quark in the loop is the bottom quark.

**THANK YOU**

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## COMPUTATIONAL DETAILS \*

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

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

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

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

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

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

$$g_S(x) = \frac{1}{x-1} - \frac{\log x}{(x-1)^2}$$

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

$$g_F(x) = \frac{x-3}{2(x-1)^2} + \frac{\log x}{(x-1)^3}$$

\*I.D., S. Fajfer, and O. Sumensari, arXiv:1910.03877.