Leptoquark induced rare decay amplitudes $h \to \tau^{\mp}\mu^{\pm}$ and $\tau \to \mu\gamma$

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arXiv:[hep-ph] 1508.01897

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Outlines

- Introduction
- Leptoquark interactions
- Amplitudes $\tau \to \mu\gamma$ and $h \to \tau^{\mp}\mu^{\pm}$
- Physics possibilities
- Concluding Remarks

Introduction

Introduction

- The width of 125 GeV Higgs is about 4 MeV. Rare decay from new physics can have measurable branching fraction.
- CMS lepton flavor violation(LFV) decay of Higgs.

$$\text{CMS:} \quad \mathrm{Br}(h \to \tau^{\mp}\mu^{\pm}) = 0.84^{+0.39}_{-0.37}\ \%,\ \ \text{excess } 2.4\ \sigma$$

$$\text{ATLAS: } \mathrm{Br}(h \to \tau^{\mp}\mu^{\pm}) = 0.77 \pm 0.62\ \%$$

- Rare decay constraint

$$\mathrm{Br}(\tau \to \mu\gamma) < 4.4 \times 10^{-8} \text{ at 90\% C.L. from BaBar experiment}$$

CMS collaboration, Phys. Lett. B749 (2015) 337-362
ATLAS collaboration, arXiv [hep-ex]:1508.03372
BaBar collaboration, Phys. Rev. Lett. 104, 021802 (2010)

Introduction

- We motivated by leptoquark(LQ) associated with 3rd generation, a top quark mass insertion in the loop diagrams.

- LQ gives amplitude for $\tau \to \mu\gamma$.

- Cancellation between two types of LQ for $\tau \to \mu\gamma$, leave detectable rate for $h \to \tau^{\mp}\mu^{\pm}$.

Leptoquark interactions

Leptoquark interactions

- We associate the new LQs with the top quark of 3rd generation.
- Mass insertion of top enhance the LFV Higgs decay mode.
- Under electroweak gauge symmetry, two types of LQs

$$\chi^{1/3}:\ SU(2)\ \text{singlet}$$

$$\Omega^T = (\Omega^{5/3}, \Omega^{2/3}):\ SU(2)\ \text{doublet}$$

$$\mathcal{L} \supset g_L^\tau \chi^{\frac{1}{3}} (Q_3)_L^T \epsilon L_{\tau,L} - g_R^\tau \chi^{\frac{1}{3}} t_R \tau_R$$

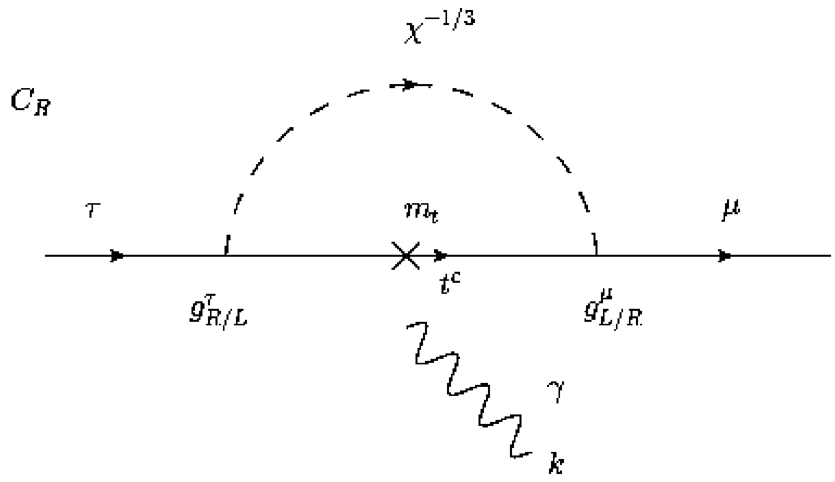
$$+ g'^{\tau}_L \Omega^T \epsilon \overline{t_R} L_{\tau,L} - g'^{\tau}_R \overline{Q_{3,L}} \tau_R \Omega \ + (\ \tau \leftrightarrow \mu\ ) + \ \text{h.c.}$$

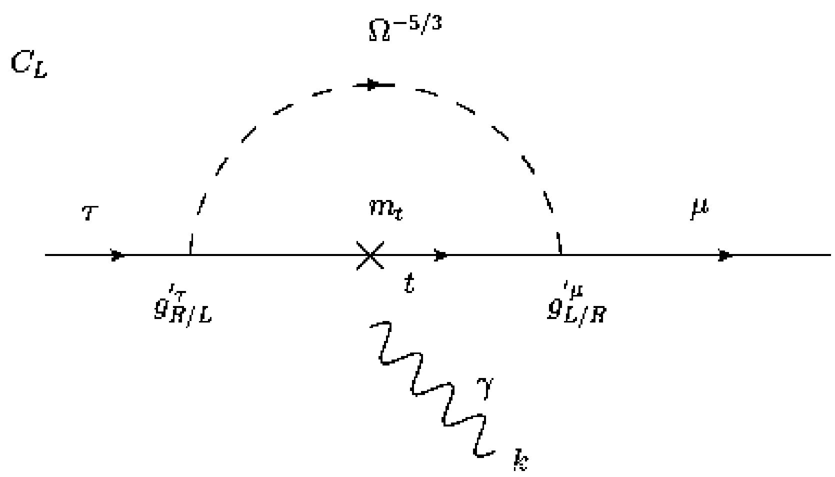
$g_{L,R}^{\tau,\mu}, g'^{\tau,\mu}_{L,R}$ are LQs couplings

Amplitude $\tau \to \mu\gamma$

Amplitude $\tau \to \mu\gamma$

- Feynman diagrams from LQs contribution to $\tau \to \mu\gamma$.





Amplitude $\tau \to \mu\gamma$

- Effective operators

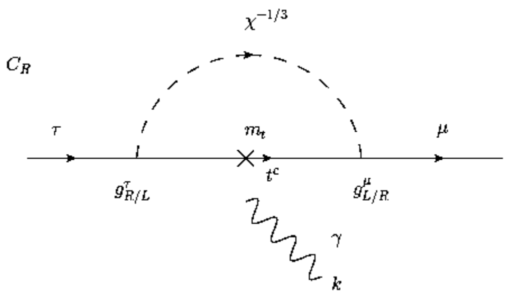
$$L_{\text{eff}} \supset \frac{e}{m_t}\left[\overline{\mu}\sigma^{\alpha\beta}\left(C_L L + C_R R\right)\tau\right]F_{\alpha\beta} + \text{h.c.}$$

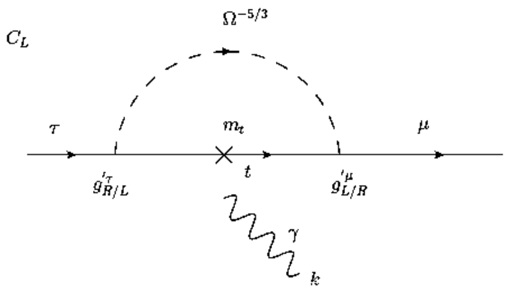
$$C_R = \frac{3_c}{32\pi^2}\left(g_R^\tau g_L^\mu x_t H_1(x_t) + g'^\tau_R\, g'^\mu_L\, x'_t\, H_2(x'_t)\right)$$

$$C_L = \frac{3_c}{32\pi^2}\left(g_L^\tau g_R^\mu x_t H_1(x_t) + g'^\tau_L\, g'^\mu_R\, x'_t\, H_2(x'_t)\right)$$

$$x_t \equiv m_t^2 / m_\chi^2$$

$$x'_t \equiv m_t^2 / m_\Omega^2$$





- Partial decay width

$$\Gamma\left(\tau \to \mu\gamma\right) = \frac{e^2}{4\pi} m_\tau \left(\frac{m_\tau^2}{m_t^2}\right)\left(\left|C_L\right|^2 + \left|C_R\right|^2\right)$$

Amplitude $h \to \tau^{\mp}\mu^{\pm}$

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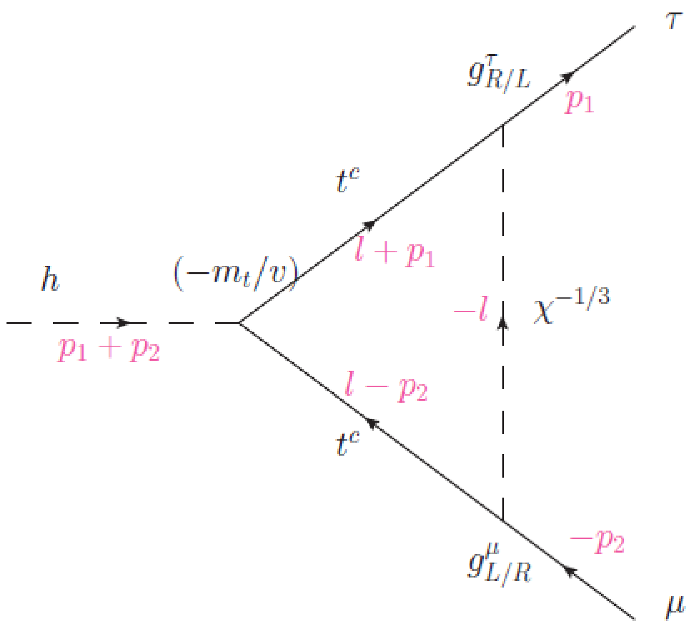
- Feynman diagrams from LQs contribution to $h \to \tau^{\mp}\mu^{\pm}$



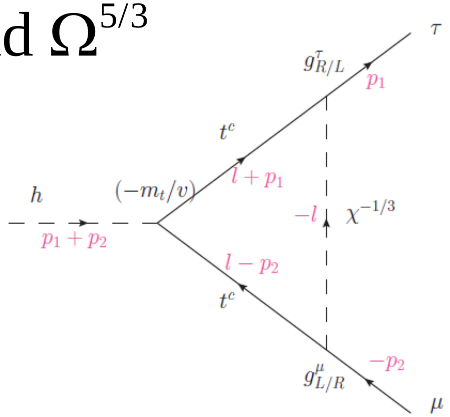
- The logarithmic divergence has to be canceled by the one-particle reducible (1PR) diagrams with bubbles in the external lepton lines.

Amplitude $h \to \tau^{\mp}\mu^{\pm}$

- The partial decay width, summing both process $h \to \tau^{\mp}\mu^{\pm}$ is

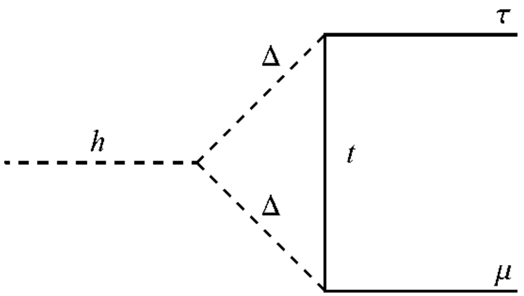
$$\Gamma\left(h \to \tau^{\mp}\mu^{\pm}\right) = \frac{9}{2048\pi^5} m_h \left(\frac{m_t}{v}\right)^2 \times\left(\left|G_\chi g_R^\tau g_L^\mu + G_\Omega g'^\tau_R g'^\mu_L\right|^2 + \left|G_\chi g_R^\mu g_L^\tau + G_\Omega g'^\mu_R g'^\tau_L\right|^2\right)$$

G_χ and G_Ω are loop functions from LQs $\chi^{1/3}$ and $\Omega^{5/3}$ running in the diagrams, respectively.



- Higgs couples to LQs from bosonic interaction

$$-\lambda_\chi H^\dagger H \chi^\dagger \chi \ .$$



I.Doršner, S.Fajfer, A.Greljo, J.F.Kamenik, N.Košnik and I.Nišandžic, JHEP 1506 (2015) 108.

- The explicit expresses of the loop functions are

$$G_\chi = (m_\chi^2+m_t^2)C_0(0,0,s,m_t^2,m_\chi^2,m_t^2)+B_0(s,m_t^2,m_t^2)-B_0(0,m_t^2,m_\chi^2)+\lambda_\chi v^2 C_0(0,0,s,m_\chi^2,m_t^2,m_\chi^2)$$

$$G_\Omega = (m_\Omega^2+m_t^2)C_0(0,0,s,m_t^2,m_\Omega^2,m_t^2)+B_0(s,m_t^2,m_t^2)-B_0(0,m_t^2,m_\Omega^2)+\lambda_\Omega v^2 C_0(0,0,s,m_\Omega^2,m_t^2,m_\Omega^2)$$

B_0 and C_0 are the Passarino-Veltman (PV) function

Physics possibilities

Physics possibilities

- Reminding the $\tau \to \mu\gamma$ and BaBar experimental constraint

$$C_R = \frac{3_c}{32\pi^2}\left(g_R^\tau g_L^\mu x_t H_1(x_t) + g'^\tau_R\, g'^\mu_L\, x'_t\, H_2(x'_t)\right)$$

$$C_L = \frac{3_c}{32\pi^2}\left(g_L^\tau g_R^\mu x_t H_1(x_t) + g'^\tau_L\, g'^\mu_R\, x'_t\, H_2(x'_t)\right)$$

$$\Gamma\left(\tau \to \mu\gamma\right) = \frac{e^2}{4\pi} m_\tau \left(\frac{m_\tau^2}{m_t^2}\right)\left(\left|C_L\right|^2 + \left|C_R\right|^2\right) \Rightarrow \mathrm{Br}\left(\tau \to \mu\gamma\right) \approx 10^{-1}$$

$\mathrm{Br}(\tau \to \mu\gamma) < 4.4\times10^{-8}$ at 90% C.L. from BaBar experiment

Physics possibilities

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$$C_R = \frac{3_c}{32\pi^2}\left(\underline{g_R^\tau g_L^\mu x_t H_1(x_t) + g'^\tau_R\, g'^\mu_L\, x'_t\, H_2(x'_t)}\right)$$

$$C_L = \frac{3_c}{32\pi^2}\left(g_L^\tau g_R^\mu x_t H_1(x_t) + g'^\tau_L\, g'^\mu_R\, x'_t\, H_2(x'_t)\right)$$

- We tune the cancellation

$$g_R^\tau g_L^\mu x_t H_1(x_t) + g'^\tau_R\, g'^\mu_L\, x'_t\, H_2(x'_t) \approx 0$$

$$g_L^\tau g_R^\mu x_t H_1(x_t) + g'^\tau_L\, g'^\mu_R\, x'_t\, H_2(x'_t) \approx 0$$

- Only one chiral mode of the muon interactions is important.

Say, $g_L^\mu \gg g_R^\mu$ and $g'^\mu_L \gg g'^\mu_R$.

Physics possibilities

- Reminding the $\tau \to \mu\gamma$ and BaBar experimental constraint

$$C_R = \frac{3_c}{32\pi^2}\left(\underline{g_R^\tau g_L^\mu} x_t H_1(x_t) + \underline{g'^\tau_R g'^\mu_L} x'_t H_2(x'_t)\right)$$

$$C_L = \frac{3_c}{32\pi^2}\left(g_L^\tau g_R^\mu x_t H_1(x_t) + g'^\tau_L g'^\mu_R x'_t H_2(x'_t)\right)$$

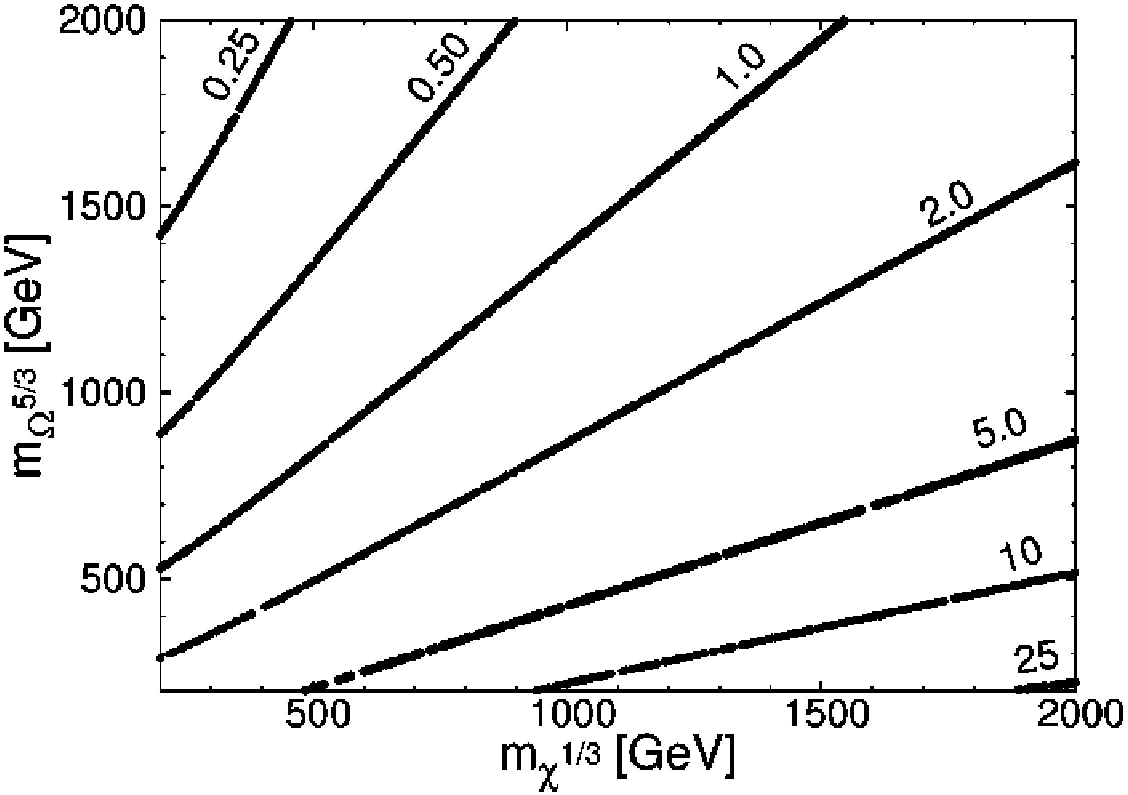
- The ratio of the couplings

$$\frac{g_R^\tau g_L^\mu}{g'^\tau_R g'^\mu_L} = -\frac{x'_t H_2(x'_t)}{x_t H_1(x_t)}$$

depend on the mass of two LQs $m_{\chi^{1/3}}$ and $m_{\Omega^{5/3}}$.

Physics possibilities

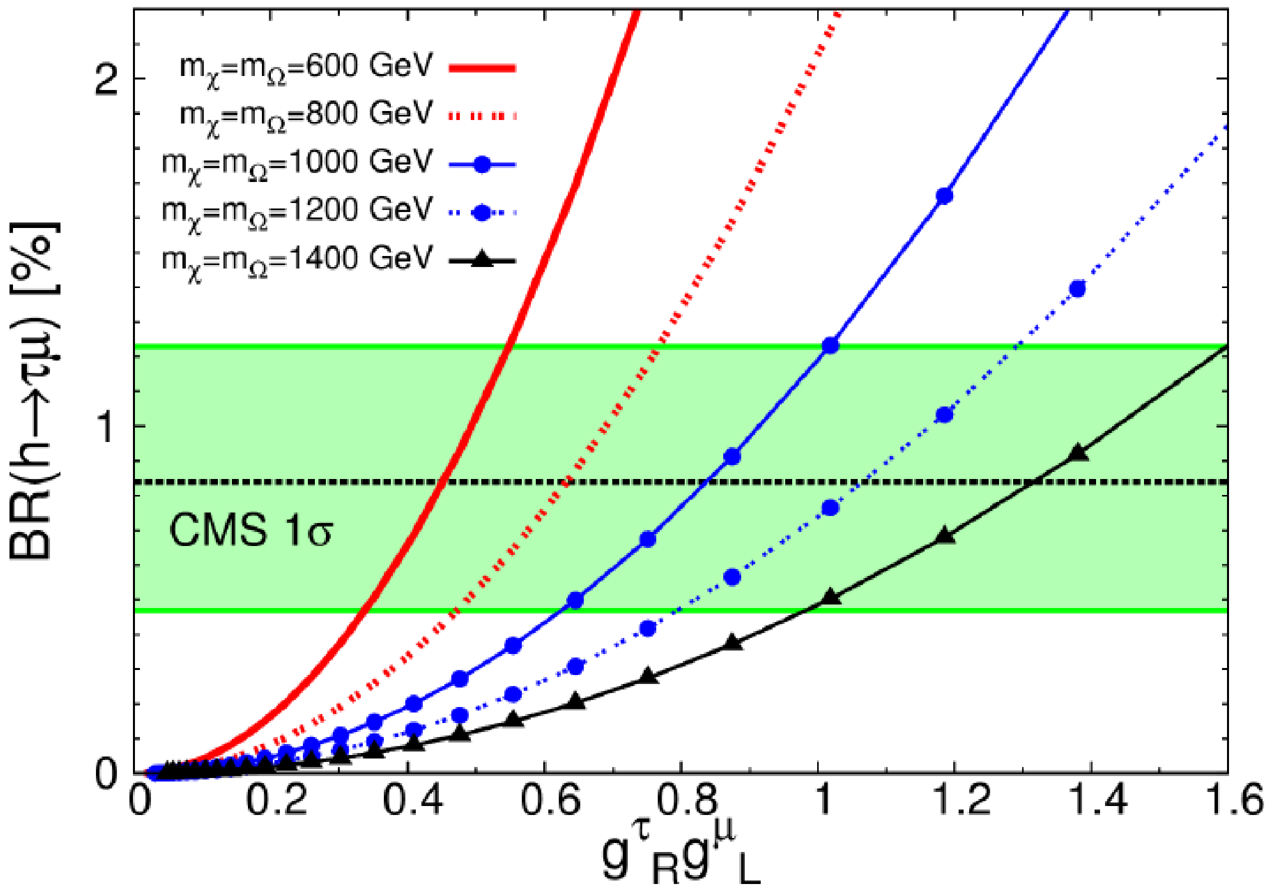
- Contour plot of the coupling ratio $\dfrac{g_R^{\tau} g_L^{\mu}}{g'^{\tau}_R\, g'^{\mu}_L} = -\dfrac{x'_t H_2(x'_t)}{x_t H_1(x_t)}$



- Large parameter space remains available for the required fine-tuning.

Physics possibilities

- Value of $\mathrm{Br}(h \to \tau^{\mp}\mu^{\pm})$ v.s $g_R^{\tau} g_L^{\mu}$ for various LQ masses when the tuned cancellation is satisfied.

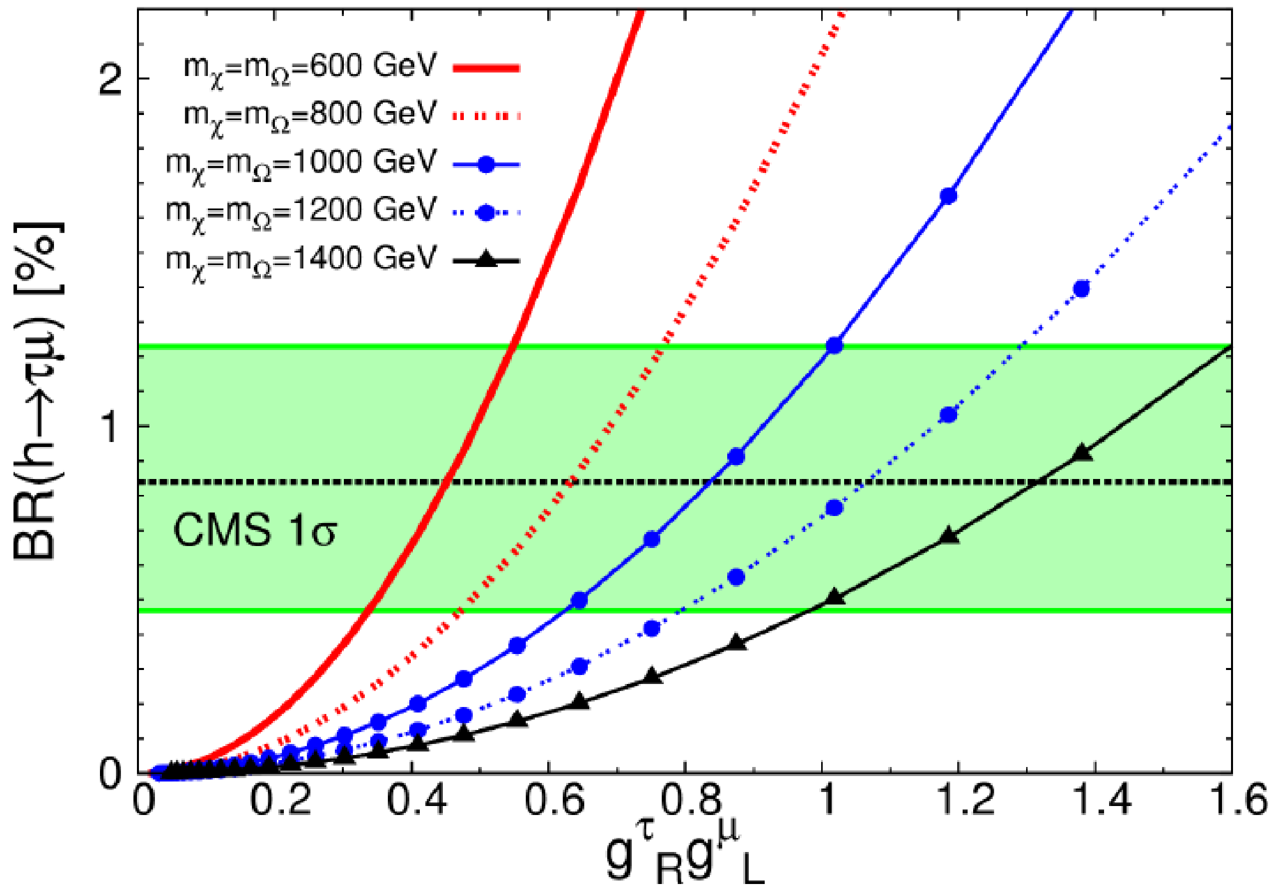


set

$$\lambda_{\chi,\Omega} = 0$$

Physics possibilities

- Branching ratio = 1% occurs for the coupling product $g_R^\tau g_L^\mu \simeq 0.3-1$ and $m_\chi = m_\Omega$ from 600 GeV to 1 TeV.



set $\lambda_{\chi,\Omega} = 0$

Concluding Remarks

Concluding Remarks

- We invoke two LQs, which couple to the 3rd generation quark and 2nd and 3rd generation leptons, for cancellation in $\tau \to \mu\gamma$ but sizable contribution to $h \to \tau^{\mp}\mu^{\pm}$.

Kingman Cheung, Phys.Rev.D64.033001.

- The contribution of LQs, we consider here, to muon g-2 is very small. We assume $g_L^\mu \gg g_R^\mu, g'^\mu_L \gg g'^\mu_R$, s.t. it is suppressed by m_μ / M_{LQ} .
- ATLAS and CMS search for the 3rd generation LQ. For $\chi^{1/3}$, mass limit is 685 GeV at 95% CL, $\Omega^T = (\Omega^{5/3}, \Omega^{2/3})$ is 740 GeV at 95% CL.

CMS Collaboration, JHEP 1507, 042 (2015)
ATLAS Collaboration, JHEP 1306, 033 (2013)
CMS Collaboration, Phys.Lett.B 739, 229 (2014)

Thank you !

Back up

Physics possibilities

- To demonstrate the level of fine-tuned cancellation in $\mathrm{Br}(\tau \to \mu\gamma)$.
- We switch off either one of the cancelling amplitudes in $\mathrm{Br}(\tau \to \mu\gamma)$ and show the individual contribution.

$$C_R = \frac{3_c}{32\pi^2}\left(g_R^\tau g_L^\mu x_t H_1(x_t) + g'^\tau_R\, g'^\mu_L\, x'_t\, H_2(x'_t)\right)$$

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$$\Gamma(\tau \to \mu\gamma) = \frac{e^2}{4\pi} m_\tau \left(\frac{m_\tau^2}{m_t^2}\right)\left(|C_L|^2 + |C_R|^2\right)$$

$\mathrm{Br}(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$ at 90% C.L. from BaBar experiment

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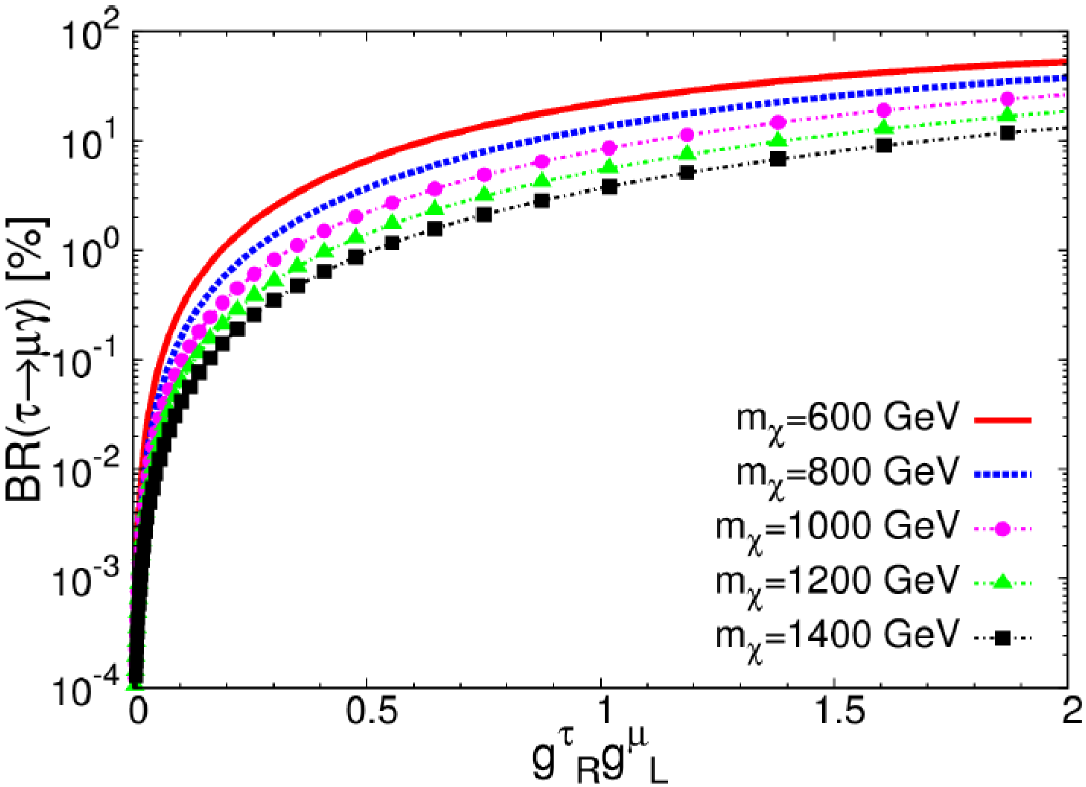
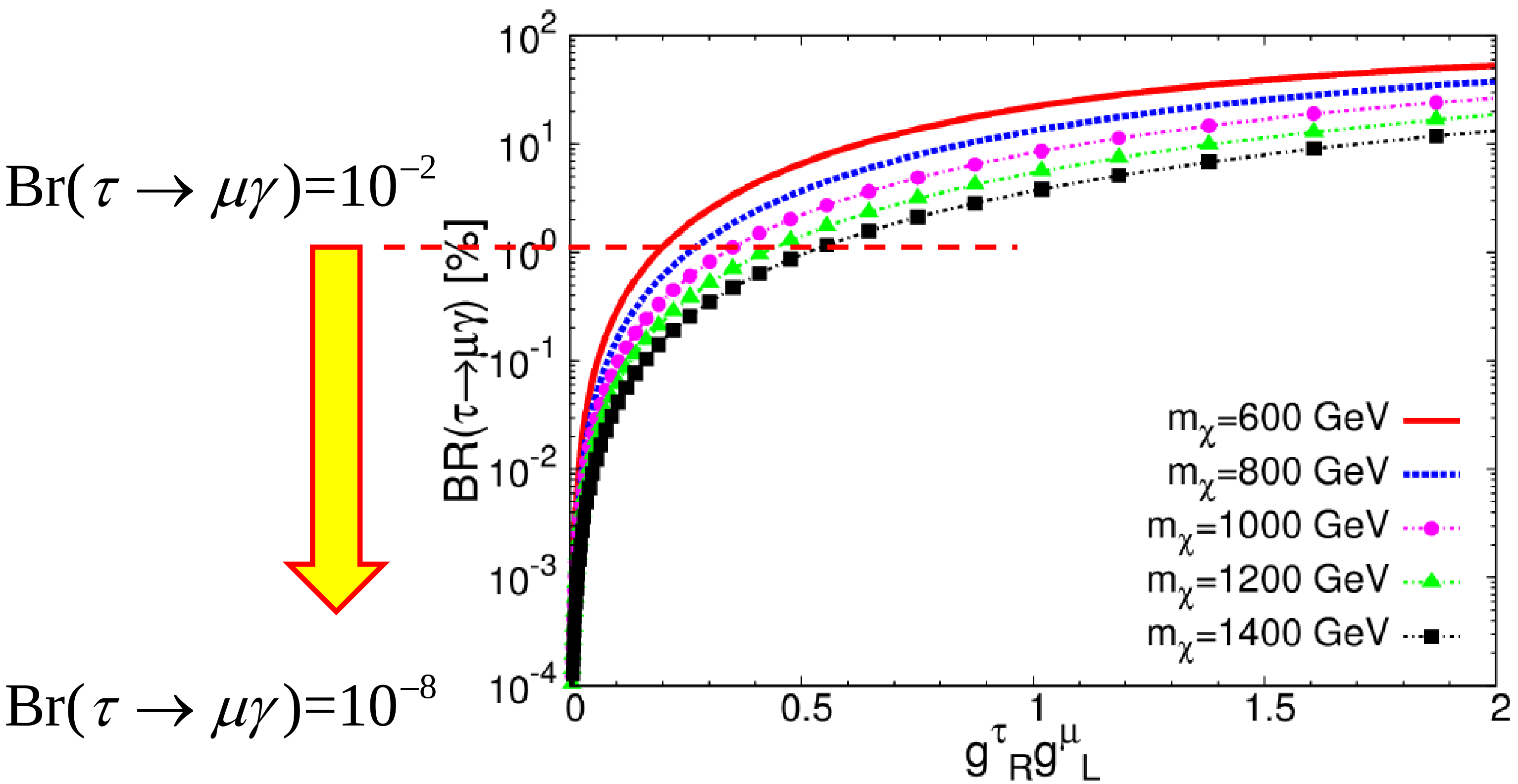


Physics possibilities

- Go down from 10^{-2} to 10^{-8} in the branching ratio, the two amplitudes are required to cancel each other by almost one part in 1000 .



Physics possibilities

- So far we set the interactions of Higgs and LQs zero

  $\lambda_\chi = \lambda_\Omega = 0$.
- Value of $\mathrm{Br}(h \to \tau^\mp \mu^\pm)$ with various $\lambda_\chi = \lambda_\Omega = \pm 1$, where the tune cancellation satisfied.