The $U(1)_{L_\mu - L_\tau}$ Model Meets the $(g-2)_\mu$ Data and Muon Neutrino Trident Scattering Again

arXiv: 2506.05511

In collaboration with **Xiao-Gang He**, **Andrew Cheek** and **Xinhui Chu**

Speaker: **Ming-Wei Li**

limw2021@sjtu.edu.cn

T.D. Lee Institute, Shanghai Jiao Tong University

June 23, 2025

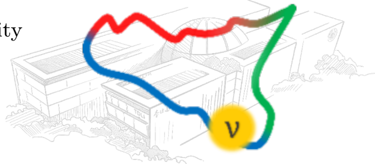
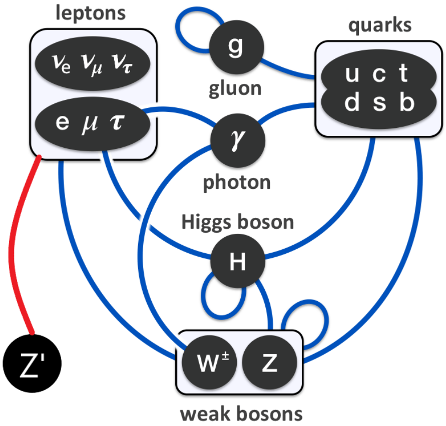


Figure 1: A possible fifth fundamental force.



One of the simplest extensions is the $U(1)_{L_\mu - L_\tau}$ model, (He et al., 1990)

$$\mathcal{L}_{Z'} = -\frac{1}{4}(Z')_{\mu\nu}(Z')^{\mu\nu} + \frac{1}{2}m_{Z'}^2 Z'_\mu Z'^\mu$$
$$- \tilde{g}\left(\bar{L}_\mu\gamma^\mu L_\mu - \bar{L}_\tau\gamma^\mu L_\tau + \bar{\mu}_R\gamma^\mu\mu_R - \bar{\tau}_R\gamma^\mu\tau_R\right) Z'_\mu.$$

where $L_\alpha = (\nu_\alpha,\ \ell_\alpha)^T$ is the $SU(2)_L$ doublet.

The new interaction terms:

$$-\tilde{g}(\bar{\mu}\gamma^\mu\mu - \bar{\tau}\gamma^\mu\tau + \bar{\nu}_\mu\gamma^\mu P_L\nu_\mu - \bar{\nu}_\tau\gamma^\mu P_L\nu_\tau)Z'_\mu\ .$$

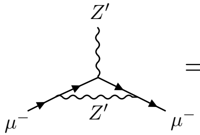
Typically, the coupling is of order $\tilde{g} \sim \mathcal{O}(g) \sim \mathcal{O}(10^{-1})$, which requires a relatively large Z' mass to satisfy experimental bounds.

Non-Standard Interaction Z' Model

$$-\tilde{g}(\bar{\mu}\gamma^\mu\mu - \bar{\tau}\gamma^\mu\tau + \bar{\nu}_\mu\gamma^\mu P_L\nu_\mu - \bar{\nu}_\tau\gamma^\mu P_L\nu_\tau)Z'_\mu \, .$$

$U(1)_{L_\mu - L_\tau}$ model involves only the μ and τ flavors,

1. Muon magnetic moment

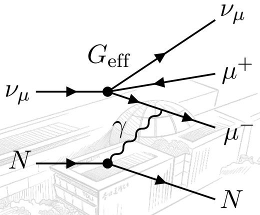


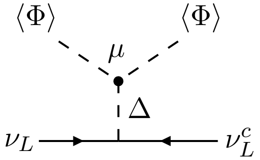
$$\Rightarrow \Delta a_\mu^{Z'} = \frac{\tilde{g}^2}{8\pi^2}\frac{m_\mu^2}{m_{Z'}^2}\int_0^1 \frac{2x^2(1-x)dx}{1-x+(m_\mu^2/m_{Z'}^2)x^2} \approx \frac{\tilde{g}^2}{12\pi^2}\frac{m_\mu^2}{m_{Z'}^2} + \mathcal{O}\left(\frac{m_\mu^4}{m_{Z'}^4}\right)$$

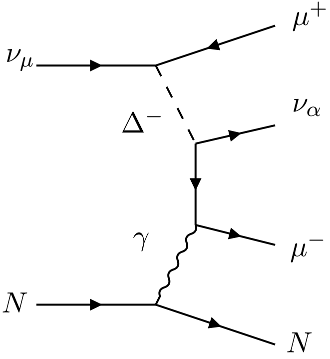
2. Muon neutrino trident scattering

$$\mathcal{L}_{\rm SM}^{\rm eff} = -\frac{g}{8m_W^2}\left(\bar{\nu}_\mu\gamma^\mu P_L\nu_\mu\right)\left(\bar{\mu}\gamma_\mu(1+4\sin^2\theta_W - \gamma^5)\mu\right)$$

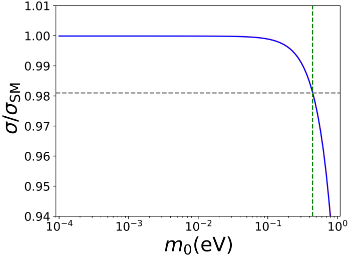
$$\mathcal{L}_{Z'}^{\rm eff} = -\frac{\tilde{g}^2}{m_{Z'}^2}\left(\bar{\nu}_\mu\gamma^\mu P_L\nu_\mu\right)\left(\bar{\mu}\gamma_\mu\mu\right)$$







arXiv: 2204.05031, Phys.Lett.B 831 (2022) 137218.



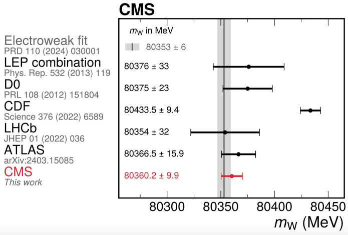
$$\rho \equiv \frac{m_W^2}{m_Z^2 \cos^2\theta_W}, \quad \rho_{SM} = 1$$

$$\rho_\Delta = 1 - \frac{2v_\Delta^2}{v^2 + 4v_\Delta^2} < 0$$

$$\rho_{CDF} = 1.0019 > 0$$

arXiv: 2412.13872

(Also Commented by Francesco Vissani)



In the heavy mass limits $\Delta a_\mu^{Z'} \approx \frac{\tilde{g}^2}{12\pi^2}\frac{m_\mu^2}{m_{Z'}^2}$, (arXiv: 2104.03281, 2506.03069)

$$\begin{cases}\Delta a_\mu^{2021} = (251 \pm 59)\times 10^{-11}\\ \Rightarrow \frac{\tilde{g}^2}{m_{Z'}^2} = (\mathbf{2.66 \pm 0.63})\times \mathbf{10^{-5}}\,\mathrm{GeV}^{-2}\end{cases}, \quad \begin{cases}\Delta a_\mu^{2025} = (39 \pm 64)\times 10^{-11}\\ \Rightarrow \frac{\tilde{g}^2}{m_{Z'}^2} = (\mathbf{4.14 \pm 6.79})\times \mathbf{10^{-6}}\,\mathrm{GeV}^{-2}\end{cases}$$

$$R_{\text{trident}} \equiv \frac{\sigma_{\text{SM}+Z'}}{\sigma_{\text{SM}}} = \frac{1+\left(1+4\sin^2\theta_W + \frac{\sqrt{2}G_{Z'}}{G_F}\right)^2}{1+\left(1+4\sin^2\theta_W\right)^2}, \quad \text{where } G_F \equiv \frac{\sqrt{2}}{8}\frac{g^2}{m_W^2},\ G_{Z'} \equiv \frac{\tilde{g}^2}{m_{Z'}^2}$$

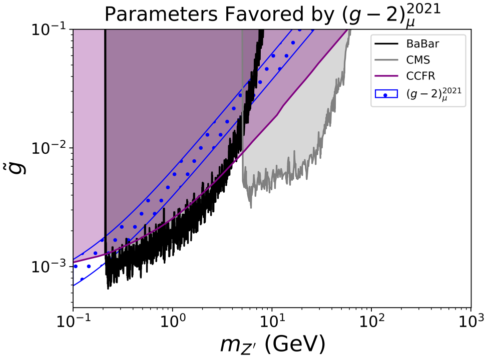
$$\Rightarrow \mathbf{R^{2021}_{\text{trident}}} = \mathbf{5.94 \pm 1.08}, \quad \mathbf{R^{2025}_{\text{trident}}} = \mathbf{1.47 \pm 0.87}. \qquad \mathbf{G_F} = \mathbf{1.166 \times 10^{-5}}\,\mathrm{GeV}^{-2}$$

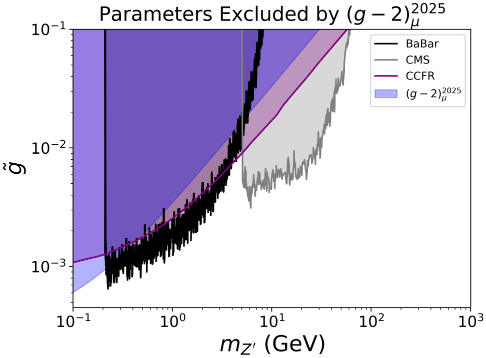
$$\begin{cases}\frac{\sigma_{\text{CHARM-II}}}{\sigma_{\text{SM}}} = 1.58 \pm 0.57\\ \frac{\sigma_{\text{CCFR}}}{\sigma_{\text{SM}}} = 0.82 \pm 0.28\\ \frac{\sigma_{\text{NuTeV}}}{\sigma_{\text{SM}}} = 0.72^{+1.73}_{-0.72}\end{cases}$$

$$\Rightarrow \sigma_{\text{exp}}/\sigma_{\text{SM}} = \mathbf{0.96 \pm 0.25},$$

- From Δa_μ^{2021}, $U(1)_{L_\mu - L_\tau}$ predicts a significant enhancement in R_{trident}, which is strongly disfavored.
- Δa_μ^{2025} yields a predicted trident ratio that is consistent with experimental data.

Constraints from $(g-2)_\mu$





The new $(g-2)\mu$ data reopens the parameter space for large $m_{Z'}$.

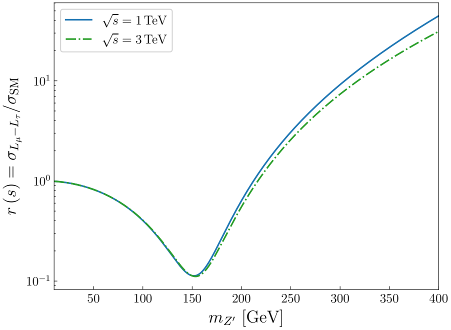
For the $U(1)_{L_\mu - L_\tau}$ model, $\mu^-\mu^+ \to \tau^-\tau^+$ will be the most consequential,

$$\mathcal{M} = \left(\frac{4\pi\alpha_{\text{em}}}{s} - \frac{G_{Z'}m_{Z'}^2}{q^2 - m_{Z'}^2 + im_{Z'}\Gamma_{Z'}}\right)(\bar{\mu}\gamma^\mu\mu)(\bar{\tau}\gamma_\mu\tau)$$
$$+ \frac{\sqrt{2}G_F m_Z^2}{q^2 - m_Z^2 + im_Z\Gamma_Z}(\bar{\mu}\gamma^\mu(g_V - g_A\gamma_5)\mu)(\bar{\tau}\gamma_\mu(g_V - g_A\gamma_5)\tau)$$

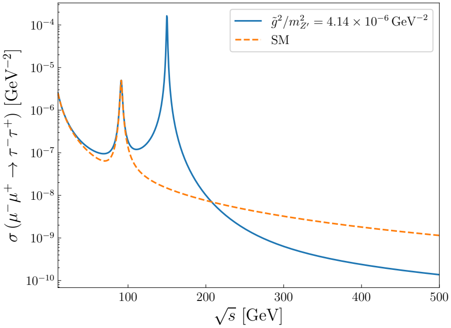
where $g_V = -\frac{1}{2} + 2\sin^2\theta_W$ and $g_A = -\frac{1}{2}$ and $\Gamma_{Z'} = \frac{G_{Z'}m_{Z'}^3}{4\pi}$.

$$\sigma_{\text{SM}+Z'} = \frac{4\pi\alpha_{\text{em}}^2}{3s} + \frac{G_{Z'}m_{Z'}^2\left((G_{Z'}m_{Z'}^2 - 8\pi\alpha_{\text{em}})s + 8\pi\alpha_{\text{em}}m_{Z'}^2\right)}{12\pi\left((s - m_{Z'}^2)^2 + m_{Z'}^2\Gamma_{Z'}^2\right)} + \frac{G_F^2 m_Z^4 s}{6\pi}\frac{(g_{\text{V}}^2 + g_{\text{A}}^2)^2}{(s - m_Z^2)^2 + m_Z^2\Gamma_Z^2}$$
$$+ \frac{2\sqrt{2}\alpha_{\text{em}}G_F m_Z^2 g_{\text{V}}^2(s - m_Z^2)}{3\left((s - m_Z^2)^2 + m_Z^2\Gamma_Z^2\right)}\left(1 - \frac{G_{Z'}m_{Z'}^2 s}{4\pi\alpha_{\text{em}}}\frac{s - m_{Z'}^2 + \frac{m_Z m_{Z'}\Gamma_Z\Gamma_{Z'}}{s - m_Z^2}}{(s - m_{Z'}^2)^2 + m_{Z'}^2\Gamma_{Z'}^2}\right)$$

Using the central value of Δa_μ^{2025}, ie. $G_{Z'}^{2025} \equiv \frac{\tilde{g}^2}{m_{Z'}^2} = 4.14 \times 10^{-6}\,\mathrm{GeV}^{-2}$,



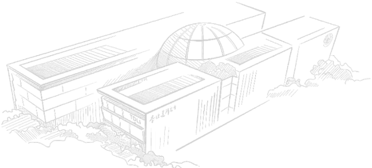
(a) $\sigma_{\mu-\tau}^{\mathrm{SM}+Z'}/\sigma_{\mu-\tau}^{\mathrm{SM}}$.



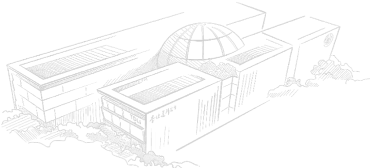
(b) $\sigma_{\mu-\tau}$ for $m_{Z'} = 150\,\mathrm{GeV}$.

Summary

1. One of the simplest extensions, the $U(1)_{L_\mu - L_\tau}$ model, introduces non-standard interactions (NSIs) that couple only to the μ and τ flavors.
2. It contributes to both $(g-2)_\mu$ and muon neutrino trident (MNT) scattering. Recent results allow for heavier Z' masses, relaxing previous bounds.
3. A future muon collider could provide a promising opportunity to directly probe the $U(1)_{L_\mu - L_\tau}$ model.



Thanks for
Your Attention



Backup

Backup