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# Flavor Specific $U(1)_{Bq-L2}$ Gauge Model for Muon g-2 and b->s Anomalies

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# Anomalies

## Fermilab

**muon anomalous magnetic dipole moment**

$$a_\mu = (g-2)/2$$

↓

$$\Delta a_\mu = a_\mu^{exp} - a_\mu^{SM} \quad 4.2\sigma$$

$$= (251 \pm 59) \times 10^{-11}$$

**Phys. Rev. Lett. 126 (2021) 141801**

## LHCb

$b \to s\bar{\mu}\mu$ **induced anomalies**

$$R_k = \frac{BR(B \to K\mu^+\mu^-)}{BR(B \to Ke^+e^-)}$$

↓

$$R_K = 0.846^{+0.042+0.013}_{-0.039-0.012} \quad 3.1\sigma$$

$$q^2 \in (1.1,\ 6)\mathrm{GeV}^2$$

**arXiv:2103.11769**

**New physics beyond the SM**

# New gauge boson

$$\begin{cases} (g-2)_\mu \\ b \to s\bar{\mu}\mu \end{cases}$$

→ **involve muon**

**2nd-3rd quark mixing**

↓

**Model with new gauge interactions**

↓

**Gauge anomaly free** $U(1)_{L_i-L_j},\ U(1)_{B-L}$

$Z'_\mu$

↓

**Flavor changing Z' interaction**

# Flavor changing Z' interaction

1. New type of quarks Phys. Rev. D 89 (2014) 095033

2. Non-trivial U(1) quantum number

   Phys. Lett. B 774 (2017) 643, arXiv:2103.13991,

   Eur. Phys. J. C 81 (2021) 56, Phys. Rev. Lett. 114(2015) 151801

3. $U(1)\text{-}U(1)_Y$ kinetic mixing

**Flavor specific $U(1)_{Bq\text{-}L2}$ gauge model**

**Only act on the 2nd generation of fermions in weak basis**

$$B_q = B_2 = 1/3,\ L_\mu = 1$$

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# Components

**Gauge group** $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B_2-L_\mu}$

$$g_s \quad g \quad g' \quad \tilde{g}$$

**Components** $H = (1, 2, 1/2)(0)$

$$Q_L = (Q_{L_1}, Q_{L_2}, Q_{L_3}) = (3, 2, 1/6)(0, 1/3, 0)$$

$$U_R = (u_{R_1}, u_{R_2}, u_{R_3}) = (3, 1, 2/3)(0, 1/3, 0)$$

$$D_R = (d_{R_1}, d_{R_2}, d_{R_3}) = (3, 1, -1/3)(0, 1/3, 0)$$

$$L_L = (L_{L_1}, L_{L_2}, L_{L_3}) = (1, 2, -1/2)(0, -1, 0)$$

$$l_R = (l_{R_1}, l_{R_2}, l_{R_3}) = (1, 1, -1)(0, -1, 0)$$

$$\nu_R = (\nu_{R_1}, \ \nu_{R_2}, \ \nu_{R_3}) = (1, 1, 0)(0 - 1, 0)$$

# Interaction with fermions

## Z' Interaction Lagrangian

$$L_{int} = \frac{1}{3}\tilde{g}\left(\bar{Q}_{L_2}\gamma^\mu Q_{L_2} + \bar{u}_{R_2}\gamma^\mu u_{R_2} + \bar{d}_{R_2}\gamma^\mu d_{R_2}\right) Z'_\mu$$
$$-\tilde{g}\left(\bar{L}_{L_2}\gamma^\mu L_{L_2} + \bar{l}_{R_2}\gamma^\mu l_{R_2} + \bar{\nu}_{R_2}\gamma^\mu \nu_{R_2}\right) Z'_\mu$$

## Yukawa Interaction and RH neutrino mass term

$$-L_{Y-mass} = \bar{Q}_L Y_H^u U_R \tilde{H} + \bar{Q}_L Y_H^d D_R H + \bar{L}_L Y_H^\nu \nu_R \tilde{H}$$
$$+\bar{L}_L Y_H^l l_R H + \frac{1}{2}\bar{\nu}_R^c \tilde{M}_R \nu_R + \text{H.c.}$$

$$Y_H^f = \begin{pmatrix} Y_{11}^f & 0 & Y_{13}^f \\ 0 & Y_{22}^f & 0 \\ Y_{31}^f & 0 & Y_{33}^f \end{pmatrix} \qquad \tilde{M}_R = \begin{pmatrix} M_{11} & 0 & M_{13} \\ 0 & 0 & 0 \\ M_{13} & 0 & M_{33} \end{pmatrix}$$

# Quark mixing

$< H >= v_0/\sqrt{2}$ → $M_f = Y_H^f v_0/\sqrt{2}$ ✗→ $V_{KM}, V_{PMNS}$

↓

**Introduce another new scalars**

**Doublets** $H_1^q : (1, 2, 1/2)(1/3), H_2^q : (1, 2, 1/2)(-1/3),$

**Singlets** $S_1 : (1, 1, 0)(1), S_2 : (1, 1, 0)(2)$

↓

**New added quark and neutrino interactions**

$$-\bar{Q}_L(Y^u_{H_1^q}\tilde{H}_1^q + Y^u_{H_2^q}\tilde{H}_2^q)U_R - \bar{Q}_L(Y^d_{H_1^q}H_1^q + Y^d_{H_2^q}H_2^q)D_R$$

$$-\frac{1}{2}\bar{\nu}_R^c(Y_{S_1}S_1 + Y_{S_2}S_2)\nu_R + \text{H.c.}$$

**Backup**

# Mass matrix

$$< H_i >= \frac{v_i}{\sqrt{2}}$$

**Quark**

$$M_u = \frac{v_0}{\sqrt{2}} Y^u_H + \frac{v^q_1}{\sqrt{2}} Y^u_{H^q_1} + \frac{v^q_2}{\sqrt{2}} Y^u_{H^q_2},$$

$$M_d = \frac{v_0}{\sqrt{2}} Y^d_H + \frac{v^q_1}{\sqrt{2}} Y^d_{H^q_1} + \frac{v^q_2}{\sqrt{2}} Y^d_{H^q_2},$$

**Lepton**

$$M_l = \frac{v_0}{\sqrt{2}} Y^l_H$$

$$M_D = (v_0/\sqrt{2}) Y^\nu_H$$

$$M_R = \tilde{M}_R + (v_{S_1}/\sqrt{2}) Y_{S_1} + (v_{S_2}/\sqrt{2}) Y_{S_2}$$

$$M_\nu = \begin{pmatrix} 0 & M_D \\ M_D^T & M_R \end{pmatrix}$$

**No charged lepton mixing** → **New doublets**

**Other constraints** **Generate mu-tau mixing**

# Lepton mixing

**Doublets** $H_1^l : (1,2,1/2)(1),\ H_2^l : (1,2,1/2)(-1),$

**New added charged lepton interactions**

$$-\left(\bar{L}_L(Y^\nu_{H_1^l}\tilde{H}_1^l + Y^\nu_{H_2^l}\tilde{H}_2^l)\nu_R + \bar{L}_L(Y^l_{H_1^l}H_1^l + Y^l_{H_2^l}H_2^l)E_R\right) + \mathrm{H.c.}$$

$$Y^\nu_{H_1^l} = \begin{pmatrix} 0 & 0 & 0 \\ Y^{\nu 21}_{H_1^l} & 0 & Y^{\nu 23}_{H_1^l} \\ 0 & 0 & 0 \end{pmatrix}, \quad Y^l_{H_1^l} = \begin{pmatrix} 0 & Y^{l12}_{H_1^l} & 0 \\ 0 & 0 & 0 \\ 0 & Y^{l32}_{H_1^l} & 0 \end{pmatrix}$$

$$Y^\nu_{H_2^l} = \begin{pmatrix} 0 & Y^{\nu 12}_{H_2^l} & 0 \\ 0 & 0 & 0 \\ 0 & Y^{\nu 32}_{H_2^l} & 0 \end{pmatrix}, \quad Y^l_{H_2^l} = \begin{pmatrix} 0 & 0 & 0 \\ Y^{l21}_{H_2^l} & 0 & Y^{l23}_{H_2^l} \\ 0 & 0 & 0 \end{pmatrix}$$

# Lepton mass matrix

$$M_l = \frac{v_0}{\sqrt{2}} Y_H^l \quad \textbf{Modify} \rightarrow \quad M_l = \frac{v_0}{\sqrt{2}} Y_H^l + \frac{v_1^l}{\sqrt{2}} Y_{H_1^l}^l + \frac{v_2^l}{\sqrt{2}} Y_{H_2^l}^l$$

$$M_D = \frac{v_0}{\sqrt{2}} Y_H^\nu \quad \rightarrow \quad M_D = \frac{v_0}{\sqrt{2}} Y_H^\nu + \frac{v_1^l}{\sqrt{2}} Y_{H_1^l}^\nu + \frac{v_2^l}{\sqrt{2}} Y_{H_2^l}^\nu$$

**Diagonalize mass matrix**

$$M_f = V_L^{f\dagger} \hat{M}_f V_R^f \,, \quad M_\nu = V^{\nu\, T} \hat{M}_\nu V^\nu$$

$$V_{KM} = V_L^u V_L^{d\dagger} \,, \quad V_{PMNS} \approx V_L^l V_{3\times 3}^{\nu\, T}$$

**Mass-squared matrix (No Z-Z' mixing)** $v_1^{q,l} = v_2^{q,l}$

$$m_Z^2 = \frac{g^2+g'^2}{4}(v_0^2 + (v_1^q)^2 + (v_2^q)^2 + (v_1^l)^2 + (v_2^l)^2)$$

$$m_Z'^2 = \tilde{g}^2(\frac{1}{(3)^2}((v_1^q)^2 + (v_2^q)^2) + (v_1^l)^2 + (v_2^l)^2 + v_{S_1}^2 + 4v_{S_2}^2)$$

# Z'-q/l interaction in the mass eigen-state

**The simplest case** $N_2 = diag(0,\ 1,\ 0)$

$$L_{int-f} = \frac{1}{3}\tilde{g}(\bar{U}_L V^u_L N_2 V^{u\dagger}_L \gamma^\mu U_L + \bar{U}_R V^u_R N_2 V^{u\dagger}_R \gamma^\mu U_R$$
$$+\bar{D}_L V^d_L N_2 V^{d\dagger}_L \gamma^\mu D_L + \bar{D}_R V^d_R N_2 V^{d\dagger}_R \gamma^\mu D_R) Z'_\mu$$
$$-\tilde{g}(\bar{l}_L V^l_L N_2 V^{l\dagger}_L \gamma^\mu l_L + \bar{l}_R V^l_R N_2 V^{l\dagger}_R \gamma^\mu l_R) Z'_\mu$$

$V^l_{L\,22} = 1$

**The general case** positive g-2

$$L_{int-sb,\mu,\nu} = -\tilde{g}\left((V^l_{L\,22} V^{l*}_{L\,22})\bar{\mu}\gamma^\mu\mu + (V^l_{L\,32} V^{l*}_{L\,32})\bar{\tau}\gamma^\mu\tau\right) Z'_\mu$$
$$-\tilde{g}\left((V^l_{L\,22} V^{l*}_{L\,32})\bar{\mu}\gamma^\mu\tau + (V^l_{L\,32} V^{l*}_{L\,22})\bar{\tau}\gamma^\mu\mu\right) Z'_\mu$$
$$+\frac{1}{3}\tilde{g}\left(V^d_{L\,22} V^{d*}_{L\,32}\bar{s}_L\gamma^\mu b_L\right) Z'_\mu$$

LH for $C_9$

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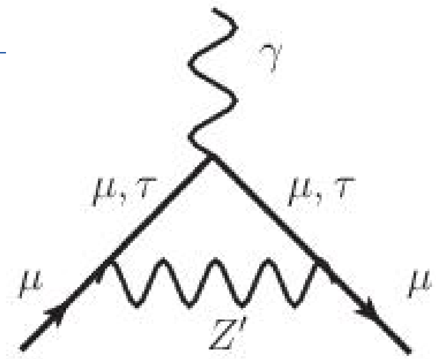
# Muon g-2




$$\Delta a_\mu = (251 \pm 59) \times 10^{-11}$$

$$\Delta a_\mu^{new} = \frac{\tilde{g}^2 m_\mu^2}{4\pi^2} \left(V^l_{L\,22} V^{l*}_{L\,22}\right) \int_0^1 dx$$

$$\times \left[ \frac{\left(V^l_{L\,32} V^{l*}_{L\,32}\right)\left(x - x^2\right)\left(x + \frac{2m_\tau}{m_\mu} - 2\right)}{m_\mu^2 x^2 + m_{Z'}^2 (1-x) + \left(m_\tau^2 - m_\mu^2\right) x} + \frac{\left(V^l_{L\,22} V^{l*}_{L\,22}\right) x^2 (1-x)}{m_\mu^2 x^2 + m_{Z'}^2 (1-x)} \right]$$

$m_{Z'} >> m_{\tau,\mu}$ $\quad$ $|V^l_{L\,32}|^2 = 1 - |V^l_{L\,22}|^2$

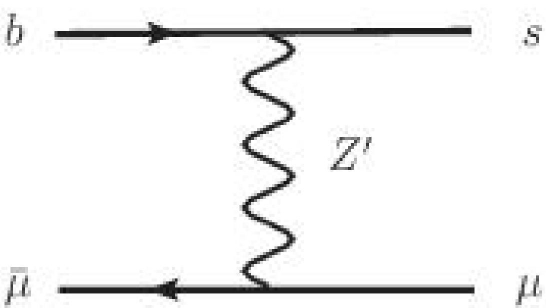
$$\frac{\tilde{g}^2}{m_{Z'}^2} = \frac{4\pi^2}{m_\mu^2} \frac{\Delta a_\mu}{|V^l_{L\,22}|^2 \left[\left(\frac{m_\tau}{m_\mu} - \frac{2}{3}\right) + |V^l_{L\,22}|^2 \left(1 - \frac{m_\tau}{m_\mu}\right)\right]}$$

$$\begin{cases} |V^l_{L\,22}| = 1 \\ |V^l_{L\,22}| = 0.15 \end{cases} \Rightarrow \begin{aligned} \tilde{g}^2 / m_{Z'}^2 &= (2.66 \pm 0.63) \times 10^{-5}\ \text{GeV}^{-2} \\ \tilde{g}^2 / m_{Z'}^2 &= (2.50 \pm 0.59) \times 10^{-5}\ \text{GeV}^{-2} \end{aligned}$$

# b anomaly

## Effective Hamiltonian

$$H_{eff} = -\frac{\tilde{g}^2}{3m_{Z'}^2}\left(V^d_{L\,22}V^{d*}_{L\,32}\right)\left(V^l_{L\,22}V^{l*}_{L\,32}\right)\left(\bar{s}_L\gamma^\mu b_L\bar{\mu}\gamma_\mu\mu\right)$$




## Standard form

$$H_{eff} = -(G_F\alpha_{em}/\sqrt{2}\pi)V_{tb}V^*_{ts}\sum_i C_iO_i$$

$$O_9 = \bar{s}_L\gamma^\mu b_L\bar{\mu}\gamma_\mu\mu,$$

$C_9 = -0.80 \pm 0.14,\ 5.7\sigma$

$$C_9^{new} = \frac{\sqrt{2}\pi\tilde{g}^2}{3m_{Z'}^2 G_F\alpha_{em}}\left(V^l_{L\,22}V^{l*}_{L\,22}\right)\frac{V^d_{L\,22}V^{d*}_{L\,32}}{V_{tb}V^*_{ts}}$$

arXiv:2103.13370

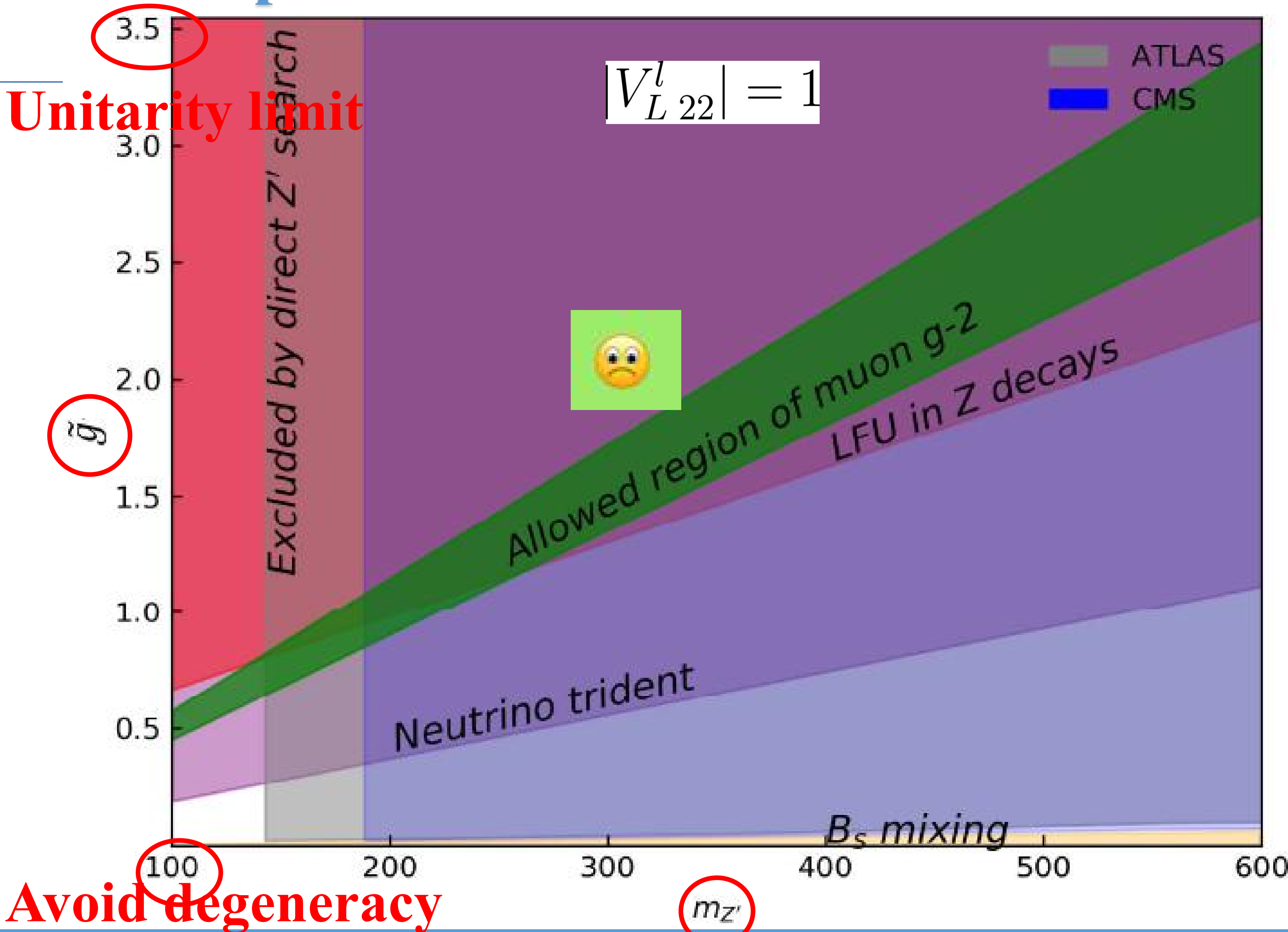
$$\frac{\tilde{g}^2}{m_{Z'}^2}\frac{V^d_{L\,22}V^{d*}_{L\,32}}{V_{tb}V^*_{ts}} = \frac{3G_F\alpha_{em}}{\sqrt{2}\pi}\frac{C_9}{|V^l_{L\,22}|^2}$$

$$\begin{cases} |V^l_{L\,22}| = 1 \\ |V^l_{L\,22}| = 0.15 \end{cases}$$

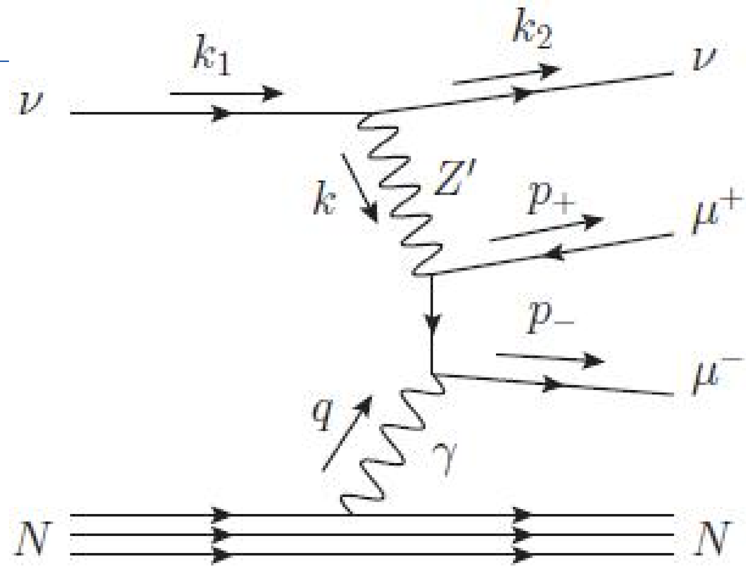
$$= (-0.46 \pm 0.08) \times 10^{-7}\ \text{GeV}^{-2}$$

$$= (-2.04 \pm 0.36) \times 10^{-6}\ \text{GeV}^{-2}$$

# The simplest case



# Neutrino trident production




$$\nu_\mu N \to \nu_\mu N \mu^+ \mu^-$$

$$\sigma^{\rm CCFR}/\sigma^{\rm SM} = 0.82 \pm 0.28$$

**PhysRevLett.66.3117**

**Suppression factor**

$$\frac{\sigma^{NP}}{\sigma^{SM}} = 1 + \frac{\left(1+4s_W^2\right)\frac{4v^2\tilde{g}^2}{m_{Z'}^2}(V^l_{L\,22}V^{l*}_{L\,22}) + \frac{4v^4\tilde{g}^4}{m_{Z'}^4}(V^l_{L\,22}V^{l*}_{L\,22})^2}{1+\left(1+4s_W^2\right)^2}$$

**decrease**

$|V^l_{L\,22}| = 1$ → $|V^l_{L\,22}| = 0.15$ → **Weaker constraint**

# LFU of Z coupling

## Lepton flavor universality of Z decay

$Z' - \mu\mu,\ Z' - \nu\nu$ → **Loop effects**

$$\frac{g_{V\mu}}{g_{Ve}} \simeq \frac{g_{A\mu}}{g_{Ae}} \simeq \left|1 + \frac{\tilde{g}^2}{(4\pi)^2}(V^l_{L\,22}V^{l*}_{L\,22})k_F(m_Z^2/m_{Z'}^2)\right|$$

**Suppression factor**

$$\frac{g_{V\nu}}{g_{Ve}} \simeq \frac{g_{A\nu}}{g_{Ae}} \simeq \left|1 + \frac{\tilde{g}^2}{(4\pi)^2}\frac{1}{3}k_F(m_Z^2/m_{Z'}^2)\right|$$

**JHEP08(2011),088**

$$g_{Ve} = -0.03817 \pm 0.00047,\ g_{Ae} = -0.50111 \pm 0.00035$$
$$g_{V\mu} = -0.0367 \pm 0.0023,\quad g_{A\mu} = -0.50120 \pm 0.00054$$
$$g_{V\nu} = g_{A\nu} = 0.5008 \pm 0.0008$$

**Strongest**

$$g_{A\mu}/g_{Ae} = 1.00018 \pm 0.00128$$

**decrease**

$|V^l_{L\,22}| = 1$ → $|V^l_{L\,22}| = 0.15$ → **Weaker constraint**

# LHC direct search

## Di-muon pair production

**Resonant Z' vector bosons decay into different final states**

**Excluded space** $\begin{cases} \text{ATLAS}: \ 150\ \text{GeV} \leq m_{Z'} \leq 5\ \text{TeV} \\ \text{CMS}: \ 200\ \text{GeV} \leq m_{Z'} \leq 5.5\ \text{TeV} \end{cases}$

**arXiv:1707.02424 [hep-ex],arXiv:1803.06292 [hep-ex]**

$|V^l_{L\ 22}| = 1$ → **Exclude all** $m_{Z'} \geq 150\ \text{GeV}$

$|V^l_{L\ 22}| = 0.15$ → **Allow to exist** $m_{Z'} \geq 150\ \text{GeV}$

$|V^l_{L\ 22}|$

**The Suppression factor opens more parameter space**

# $B_S$ mixing

$$B_s - \bar{B}_s$$

$$\frac{M_{12}}{M_{12}^{SM}} = 1 + \frac{\tilde{g}^2}{m_{Z'}^2}\left(\frac{V^d_{L\,22}V^{d*}_{L\,32}}{V_{tb}V^*_{ts}}\right)^2\left(\frac{9g^2 S_0}{16\pi^2 v^2}\right)^{-1} \qquad S_0 \simeq 2.3$$

**arXiv:1008.1593 [hep-ph],arXiv:1211.1896 [hep-ph]**

$$\left|\frac{\tilde{g}}{m_{Z'}}\frac{V^d_{L\,22}V^{d*}_{L\,32}}{V_{tb}V^*_{ts}}\right| = \frac{3g}{4\pi v}\sqrt{\left(\frac{M_{12}}{M_{12}^{SM}} - 1\right)S_0}$$

$$M_{12}/M_{12}^{SM} = 0.959^{+0.062}_{-0.078}$$

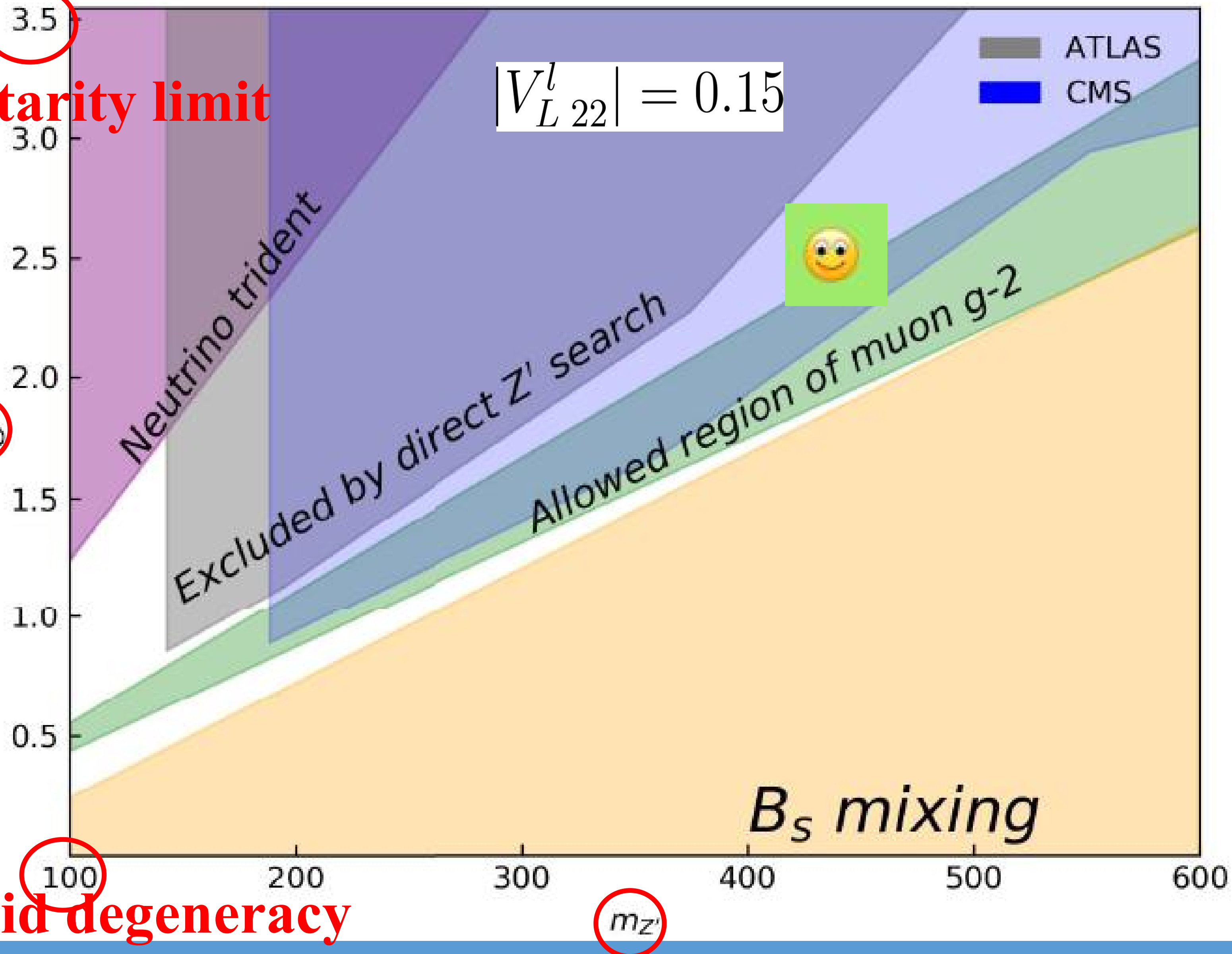
**Combine $C_9$**

$$\frac{\tilde{g}}{m_{Z'}} = \frac{4vG_F\alpha_{em}}{g}\frac{-C_9}{|V^l_{L\,22}|^2}\frac{1}{\sqrt{2S_0\left(\frac{M_{12}}{M_{12}^{SM}}-1\right)}}$$

$$\begin{cases} |V^l_{L\,22}| = 1 \\ |V^l_{L\,22}| = 0.15 \end{cases} \Rightarrow \begin{matrix} \tilde{g}/m_{Z'} \geq 1.08\times10^{-4} \\ \tilde{g}/m_{Z'} \geq 4.81\times10^{-3} \end{matrix}$$

# The general case

**Unitarity limit**




**Avoid degeneracy**

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# U(1) kinetic mixing

**U(1)$_Y$-U(1) kinetic mixing** $(1/2)\delta B^{\mu\nu} Z'_{\mu\nu}, \quad |\delta| < 1$

$$B = \cos\theta_W A - \sin\theta_W Z$$

## Mixing of mass eigen-state

$$\begin{pmatrix} Z^m \\ Z'^m \end{pmatrix} = \begin{pmatrix} \cos\xi & \sin\xi \\ -\sin\xi & \cos\xi \end{pmatrix} \begin{pmatrix} Z \\ Z' \end{pmatrix}$$

$$\tan 2\xi = \frac{2m_Z^2 \delta \sin\theta_W / \sqrt{1-\delta^2}}{m_Z^2 - (m_Z^2 \delta^2 \sin^2\theta_W + m_{Z'}^2)/(1-\delta^2)}$$

↓

$$\xi \approx \frac{m_Z^2 \delta \sin\theta_W}{m_Z^2 - m_{Z'}^2}$$

# Interaction terms

## In the mass eigen-state

$$L_{int} = J^{\mu}_{em} A^{m}_{\mu}$$
$$+ \left( -\frac{s_\xi \delta \cos\theta_W}{\sqrt{1-\delta^2}} J^{\mu}_{em} + (c_\xi + \frac{s_\xi \delta \sin\theta_W}{\sqrt{1-\delta^2}}) J^{\mu}_{Z} + \frac{s_\xi}{\sqrt{1-\delta^2}} J^{\mu}_{Z'} \right) Z^{m}_{\mu}$$
$$+ \left( -\frac{c_\xi \delta \cos\theta_W}{\sqrt{1-\delta^2}} J^{\mu}_{em} - (s_\xi - \frac{c_\xi \delta \sin\theta_W}{\sqrt{1-\delta^2}}) J^{\mu}_{Z} + \frac{c_\xi}{\sqrt{1-\delta^2}} J^{\mu}_{Z'} \right) Z'^{m}_{\mu}$$

**Current**

$$J^{\mu}_{em} = -eQ^f \bar{f} \gamma^\mu f$$
$$J^{\mu}_{Z} = -(g/2\cos\theta_W) \bar{f} \gamma^\mu (g^f_V - g^f_A \gamma_5) f$$
$$g^f_V = I^f_3 - 2Q^f \sin^2\theta_W, \quad g_A = I^f_3$$
$$J^{\mu}_{Z'} = -\tilde{g}(V^l_{L\,22} V^{l*}_{L\,22}) \bar{\mu} \gamma^\mu \mu$$

# Kinetic mixing effects

## g-2

**First order correction**

$$\Delta a_\mu^{mixing}(\delta) = 0$$

**Second order correction**

$$\frac{\tilde{g}^2}{4\pi^2}\frac{m_\mu^2}{m_Z^2}\left(\frac{m_Z^2}{m_Z^2 - m_{Z'}^2}\right)^2 \delta^2 \sin^2\theta |V_{L\ 22}^l|^2$$
$$\times \left[ |V_{L\ 32}^l|^2 \left(\frac{m_\tau}{m_\mu} - \frac{2}{3}\right) + \frac{1}{3}|V_{L\ 22}^l|^2 \right]$$

↓

**Neglect**

## b anomaly

$$\bar{s}bZ \to Z - Z' \to Z'\mu\bar{\mu}$$

$$C_9^{loop} = 2\cos\theta_W \frac{\tilde{g}(V_{L\ 22}^l V_{L\ 22}^{l*})}{e} \times \frac{m_Z^2 \delta}{m_Z^2 - m_{Z'}^2} C_0(m_t^2/m_W^2)$$

$$\begin{cases} m_{Z'} \in [100, 600]\text{GeV} \\ |V_{L\ 22}^l| = 0.15 \end{cases}$$

↓

$$C_9^{loop} = [-1.74\delta,\ -0.05\delta]$$

# Conclusions

1. We construct a flavor specific gauge model to explain muon g-2 and b anomalies simultaneously.

2. The original Z'-$q_2$/$l_2$ interaction in weak basis can develop mixing in mass eigen-state basis.

3. The introduced substantial mu-tau mixing induces the suppressed factor $V^l_{L22}$ to make other processes satisfied so that some viable paramater space emerges.

4. The model can be tested at a high energy muon collider.

# Thanks!

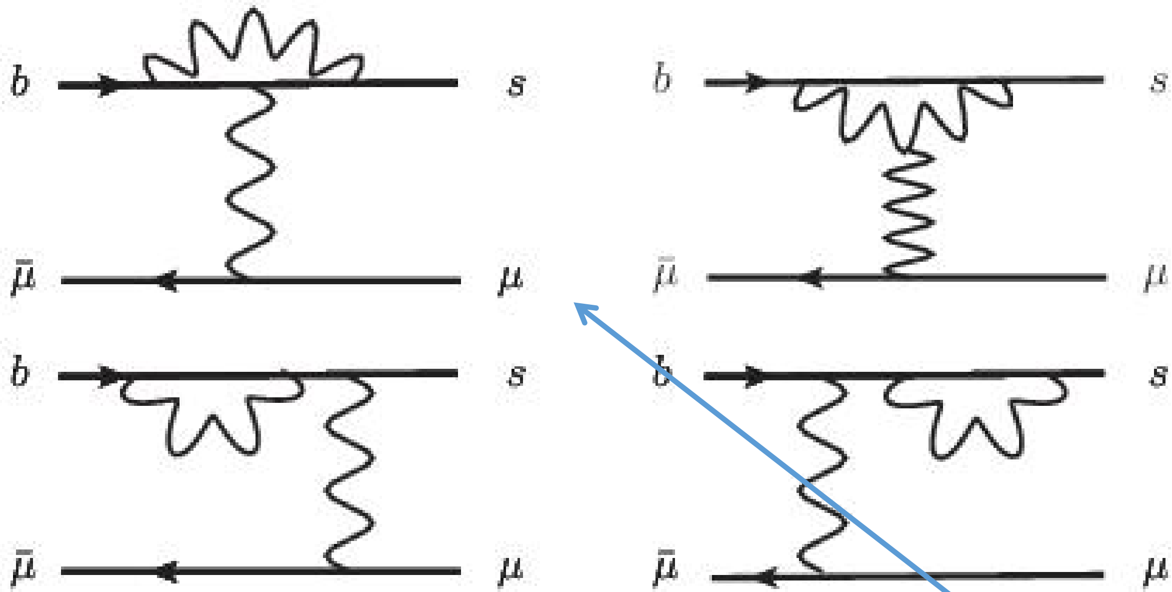
# Yukawa coefficients

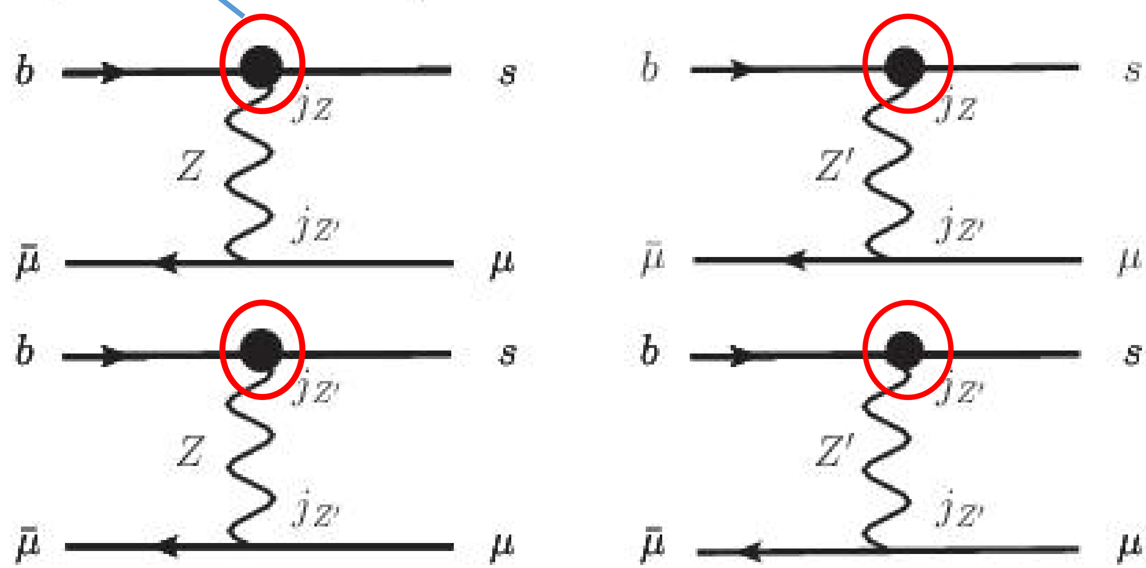
$$Y^u_{H_1} = \begin{pmatrix} 0 & Y^{u12}_{H_1} & 0 \\ 0 & 0 & 0 \\ 0 & Y^{u32}_{H_1} & 0 \end{pmatrix}, \quad Y^d_{H_1} = \begin{pmatrix} 0 & 0 & 0 \\ Y^{d21}_{H_1} & 0 & Y^{d23}_{H_1} \\ 0 & 0 & 0 \end{pmatrix}$$

$$Y^u_{H_2} = \begin{pmatrix} 0 & 0 & 0 \\ Y^{u21}_{H_2} & 0 & Y^{u23}_{H_2} \\ 0 & 0 & 0 \end{pmatrix}, \quad Y^d_{H_2} = \begin{pmatrix} 0 & Y^{d12}_{H_2} & 0 \\ 0 & 0 & 0 \\ 0 & Y^{d32}_{H_2} & 0 \end{pmatrix}$$

$$Y_{S_1} = \begin{pmatrix} 0 & Y^{12}_{S_1} & 0 \\ Y^{12}_{S_1} & 0 & Y^{23}_{S_1} \\ 0 & Y^{23}_{S_1} & 0 \end{pmatrix}, \quad Y_{S_2} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & Y^{22}_{S_2} & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

# b anomaly correction by kinetic mixing




$$C_0(x) = \frac{x}{8} \times \left( \frac{6-x}{1-x} + \frac{3x+2}{(1-x)^2} \ln x \right)$$