Vector Leptoquark and W mass anomaly

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Reference: arXiv:2204.05942

Rapid Response Workshop on W Boson Mass Anomaly, 27th May 2022

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Introduction

- Taking m_Z and G_F as experimental inputs, the evaluation of Δr within the SM or BSM can be translated into a theoretical prediction for the W-boson mass:

$$m_{\rm W}^2 = \frac{1}{2}\, m_Z^2 \left[1 + \sqrt{1 - \frac{4\,\pi\alpha_{\rm em}}{\sqrt{2}\,G_F\, m_Z^2}\,[1 + \Delta\, r(m_{\rm W}^2)]}\right]$$

D.Lopez-Val and T.Robens, arXiv: 1406.1043

- The expression of Δr can be recast as

$$\Delta r = \underline{\Delta\alpha} - \frac{c_W^2}{s_W^2}\,\delta\rho + \Delta r_{\rm rem}$$

Leading QED light-fermion corrections

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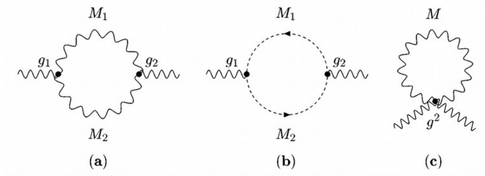

Static contribution to the gauge boson self-energy

$$\frac{\Sigma_{\rm Z}(0)}{m_{\rm Z}^2} - \frac{\Sigma_{\rm W}(0)}{m_{\rm W}^2} \equiv \delta\rho$$

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SM top-quark contribution gives: $\delta\rho_{\rm SM}^{[t]} = \frac{3 G_F m_t^2}{8\sqrt{2}\,\pi^2}$

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Remainder term: condenses the remaining effects.

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$$\Delta r = \Delta\alpha - \frac{c_W^2}{s_W^2}\,\delta\rho + \Delta r_{\mathrm{rem}}$$

in SM, we have $\Delta\alpha = 0.06, \quad \Delta r_{\mathrm{rem}} = 0.01$.

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- The most recent measurements:

$$\alpha_{\mathrm{em}} = 1/137.035999084, \quad G_F = 1.1663787 \times 10^{-5}\ \mathrm{GeV}^{-2},$$
$$m_t = 172.89\ \mathrm{GeV}, \quad m_Z = 91.1876\ \mathrm{GeV}, \quad m_H = 125.25\ \mathrm{GeV}$$

$$m_W^{\mathrm{SM}} = 80357 \pm 6\ \mathrm{MeV} \qquad m_W^{\mathrm{CDFII}} = 80433.5 \pm 9.4\ \mathrm{MeV}$$

T.Aaltonen et al. CDF: Science 376, 170 (2022)

Vector Leptoquark: V2

Iso-doublet Vector Leptoquark: V2

- The weak iso-doublet vector LQ V_2 with SM quantum numbers $(\bar{\mathbf{3}}, \mathbf{2}, 5/6)$

$$V_2 = \begin{pmatrix} V^{+4/3} \\ V^{+1/3} \end{pmatrix}$$

- Its interactions with SM fermions:

$$\begin{aligned}
\mathcal{L}_{Vff} &= X_{ij}^{RL} \epsilon^{ab} \, \overline{d_R^{c,i}} \, \gamma^\mu V_\mu^a \, L_L^{j,b} + X_{ij}^{LR} \epsilon^{ab} \, \overline{Q_L^{c,i,a}} \, \gamma^\mu V_\mu^b \, e_R^j + h.c. \\
&= X_{ij}^{RL} \left[\overline{d_R^{c,i}} \, \gamma^\mu \ell_L^j \, V_\mu^{+4/3} - \overline{d_R^{c,i}} \, \gamma^\mu \nu_L^j V_\mu^{+1/3} \right] \\
&\quad + X_{ij}^{LR} \left[\overline{u_L^{c,i}} \, \gamma^\mu e_R^j \, V_\mu^{+1/3} - \overline{d_L^{c,i}} \, \gamma^\mu e_R^j \, V_\mu^{+4/3} \right] + h.c.
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- Its interactions with SM fermions.
- It had been used to explain the B-anomalies:

$$R_K = \frac{\mathrm{BR}(B \to K\mu^+\mu^-)}{\mathrm{BR}(B \to Ke^+e^-)}, \quad R_{K*} = \frac{\mathrm{BR}(B \to K^*\mu^+\mu^-)}{\mathrm{BR}(B \to K^*e^+e^-)}$$

$$R_K = 0.846\,^{+0.042}_{-0.039}\,^{+0.013}_{-0.012}, \quad \text{for } 1.1\ \mathrm{GeV}^2 < q^2 < 6\ \mathrm{GeV}^2,$$

$$R_{K^*} = \begin{cases} 0.66\,^{+0.11}_{-0.07} \pm 0.03 & 0.045\ \mathrm{GeV}^2 < q^2 < 1.1\ \mathrm{GeV}^2, \\ 0.69\,^{+0.11}_{-0.07} \pm 0.05 & 1.1\ \mathrm{GeV}^2 < q^2 < 6.0\ \mathrm{GeV}^2, \end{cases}$$

$$R_D = \frac{\mathrm{BR}(B \to D\tau\nu)}{\mathrm{BR}(B \to D\ell\nu)} = 0.340 \pm 0.027 \pm 0.013,$$

$$R_{D^*} = \frac{\mathrm{BR}(B \to D^*\tau\nu)}{\mathrm{BR}(B \to D^*\ell\nu)} = 0.295 \pm 0.011 \pm 0.008,$$

Iso-doublet Vector Leptoquark: V2

- The Wilson coefficients from V_2 on the interactions with electron are

$$
\begin{aligned}
C_9^{bsee} &= +C_{10}^{bsee} = -\frac{4\pi^2}{e^2}\frac{v^2}{M_{V_2}^2}\frac{X_{31}^{LR}X_{21}^{LR*}}{V_{ts}^*V_{tb}}\,,\\
C_9^{\prime bsee} &= -C_{10}^{\prime bsee} = -\frac{4\pi^2}{e^2}\frac{v^2}{M_{V_2}^2}\frac{X_{31}^{RL}X_{21}^{RL*}}{V_{ts}^*V_{tb}}\,,\\
C_S^{bsee} &= -C_P^{bsee} = \frac{4\pi^2}{e^2}\frac{2v^2}{M_{V_2}^2}\frac{X_{31}^{RL}X_{21}^{LR*}}{V_{ts}^*V_{tb}}\,,\\
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\end{aligned}
$$

$$\mathcal{L}_{bs\ell\ell} \supset \frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{e^2}{16\pi^2} \sum_i \left[C_i\mathcal{O}_i + C_i'\mathcal{O}_i'\right] + h.c.\,,$$

$$
\begin{aligned}
&\mathcal{O}_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\ell)\,, && \mathcal{O}_9' = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu\ell)\,,\\
&\mathcal{O}_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma^5\ell)\,, && \mathcal{O}_{10}' = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu\gamma^5\ell)\,,\\
&\mathcal{O}_S = (\bar{s}\, P_R b)(\bar{\ell}\ell)\,, && \mathcal{O}_S' = (\bar{s}P_L b)(\bar{\ell}\ell)\,,\\
&\mathcal{O}_P = (\bar{s}P_R b)(\bar{\ell}\gamma_5\ell)\,, && \mathcal{O}_P' = (\bar{s}P_L b)(\bar{\ell}\gamma_5\ell)\,,
\end{aligned}
$$

$$C_9 = +C_{10}$$

Iso-doublet Vector Leptoquark: V2

- The Wilson coefficients global fits:

W.Altmannshofer and P.Stangl: arXiv 2103.13370

Wilson coefficient	$b \to s\mu\mu$ best fit	$b \to s\mu\mu$ pull	LFU, $B_s \to \mu\mu$ best fit	LFU, $B_s \to \mu\mu$ pull	all rare B decays best fit	all rare B decays pull
$C_9^{bs\mu\mu}$	$-0.75^{+0.22}_{-0.23}$	3.4σ	$-0.74^{+0.20}_{-0.21}$	4.1σ	$-0.73^{+0.15}_{-0.15}$	5.2σ
$C_{10}^{bs\mu\mu}$	$+0.42^{+0.23}_{-0.24}$	1.7σ	$+0.60^{+0.14}_{-0.14}$	4.7σ	$+0.54^{+0.12}_{-0.12}$	4.7σ
$C_9^{\prime bs\mu\mu}$	$+0.24^{+0.27}_{-0.26}$	0.9σ	$-0.32^{+0.16}_{-0.17}$	2.0σ	$-0.18^{+0.13}_{-0.14}$	1.4σ
$C_{10}^{\prime bs\mu\mu}$	$-0.16^{+0.16}_{-0.16}$	1.0σ	$+0.06^{+0.12}_{-0.12}$	0.5σ	$+0.02^{+0.10}_{-0.10}$	0.2σ
$C_9^{bs\mu\mu} = C_{10}^{bs\mu\mu}$	$-0.20^{+0.15}_{-0.15}$	1.3σ	$+0.43^{+0.18}_{-0.18}$	2.4σ	$+0.05^{+0.12}_{-0.12}$	0.4σ
$C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu}$	$-0.53^{+0.13}_{-0.13}$	3.7σ	$-0.35^{+0.08}_{-0.08}$	4.6σ	$-0.39^{+0.07}_{-0.07}$	5.6σ
C_9^{bsee}			$+0.74^{+0.20}_{-0.19}$	4.1σ	$+0.75^{+0.20}_{-0.19}$	4.1σ
C_{10}^{bsee}			$-0.67^{+0.17}_{-0.18}$	4.2σ	$-0.66^{+0.17}_{-0.17}$	4.3σ
$C_9^{\prime bsee}$			$+0.36^{+0.18}_{-0.17}$	2.1σ	$+0.40^{+0.19}_{-0.18}$	2.3σ
$C_{10}^{\prime bsee}$			$-0.31^{+0.16}_{-0.16}$	2.1σ	$-0.30^{+0.15}_{-0.16}$	2.0σ
$C_9^{bsee} = C_{10}^{bsee}$			$-1.39^{+0.26}_{-0.26}$	4.0σ	$-1.28^{+0.24}_{-0.23}$	4.1σ
$C_9^{bsee} = -C_{10}^{bsee}$			$+0.37^{+0.10}_{-0.10}$	4.2σ	$+0.37^{+0.10}_{-0.10}$	4.3σ

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$$\mathcal{O}_P = (\bar{s} P_R b)(\bar{\ell}\gamma_5 \ell), \quad \mathcal{O}_P' = (\bar{s} P_L b)(\bar{\ell}\gamma_5 \ell),$$

- B-meson global fit preferred $C_9 = -C_{10}$ for muon but $C_9 = +C_{10}$ for electron.
- Therefore, we focus the interactions with electron.

Iso-doublet Vector Leptoquark: V2

- Bs → l+l- in terms of Wilson coefficients:

N.Kosnik: arXiv 1206.2970

$$\mathrm{Br}(B_s \to \ell^+\ell^-) = \tau_{B_s} f_{B_s}^2 m_{B_s}^3 \frac{G_F^2 |V_{tb}V_{ts}^*|^2 e^4}{(4\pi)^5} \sqrt{1 - 4m_\ell^2/m_{B_s}^2} \times \left[\frac{m_{B_s}^2}{m_b^2} |C_S - C_S'|^2 \left(1 - \frac{4m_\ell^2}{m_{B_s}^2}\right) + \left| \frac{m_{B_s}}{m_b} (C_P - C_P') + \frac{2m_\ell}{m_{B_s}} (C_{10}^{\mathrm{SM}} + C_{10} - C_{10}') \right|^2 \right]$$

- Bs → l+l- experimental measurments:

W.Altmannshofer and P.Stangl: arXiv 2103.13370

$$\mathrm{Br}(B_s \to \mu^+\mu^-) = (3.09^{+0.48}_{-0.44}) \times 10^{-9},$$
$$\mathrm{Br}(B_s \to e^+e^-) < 9.4 \times 10^{-9} \text{ at } 90\% \text{ C.L from PDG},$$

Iso-doublet Vector Leptoquark: V2

- Its gauge interaction:

$$\mathcal{L}_{V_2} = -\frac{1}{2} V^{\dagger}_{\mu\nu} V^{\mu\nu} + M_V^2 V^{\dagger}_{\mu} V^{\mu} + i g_3 V^{\dagger}_{\mu} \frac{\lambda^A}{2} V_\nu G^{A,\mu\nu} + i g_2 V^{\dagger}_{\mu} \frac{\tau^k}{2} V_\nu W^{k,\mu\nu} + i g_1 V^{\dagger}_{\mu} Y V_\nu B^{\mu\nu}$$

$$V_{\mu\nu} = \sum_{i=1,2} D_\mu V^i_\nu - D_\nu V^i_\mu$$

$$D_\mu = \partial_\mu + i g_1 Y B_\mu + i g_2 \frac{\tau^k}{2} W^k_\mu + i g_3 \frac{\lambda^A}{2} G^A_\mu$$

- Extracting the triple gauge vertices:

$$\mathcal{L}_{\mathrm{V^\dagger VA}} = e Q_V \left[g_{\alpha\beta}(p-p')_\gamma + g_{\beta\gamma}(p'-k)_\alpha + g_{\gamma\alpha}(k-p)_\beta \right] \lambda^\alpha \lambda'^\beta \epsilon^\gamma$$

$$\mathcal{L}_{VVZ} = \frac{g}{c_w}\left(T_3 - Q s_w^2\right) \times [\text{the same form of momenta as the photon}]$$

$$\mathcal{L}_{VVW} = \frac{g}{\sqrt{2}} \times [\text{the same form of momenta as the photon}]$$

Iso-doublet Vector Leptoquark: V2

- Its gauge interactions contribute to *I) lepton g-2, II)* $\ell_i \to \ell_j \gamma$ *,and III) W boson mass*.
- Lepton g-2:

$$\Delta a_\ell = -\frac{N_C}{16\pi^2}\left[4\mathcal{R}e(X_{3\ell}^{LR*}X_{3\ell}^{RL})\frac{m_b m_\ell}{M_V^2}(Q_V+Q_{b^c})+2(|X_{3\ell}^{LR}|^2+|X_{3\ell}^{RL}|^2)\frac{m_\ell^2}{M_V^2}\left(\frac{5}{6}Q_V+\frac{2}{3}Q_{b^c}\right)\right]$$

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- Muon g-2 from E989 experiment at Fermilab:

$$\Delta a_\mu = (25.1 \pm 5.9) \times 10^{-10}$$

→ $X^{\rm LR}_{32} X^{\rm RL}_{32}$

- Electron g-2 was used to determine the fine-structure: constant resulting in two theory predictions, which deviate from experimental measurement

$$\Delta a_e^{\rm LKB} = a_e^{\rm exp} - a_e^{\rm LKB} = (4.8 \pm 3.0) \times 10^{-13}$$
$$\Delta a_e^{\rm B} = a_e^{\rm exp} - a_e^{\rm B} = (-8.8 \pm 3.6) \times 10^{-13}$$

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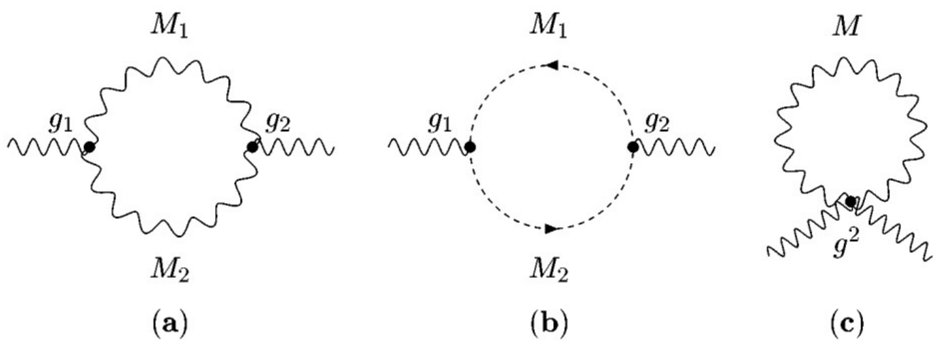
Stefan Pokorski, Gauge Field Theory 2nd edition



$$
\begin{aligned}
&\left\{ \frac{\Pi^T_{WW}(0)}{m_W^2} - \frac{\Pi^T_{ZZ}(0)}{m_Z^2}\bigg|_{V+4/3} - \frac{\Pi^T_{ZZ}(0)}{m_Z^2}\bigg|_{V+1/3} \right\} \Big/ \frac{g^2}{(4\pi)^2} \\
&= \frac{1}{2m_W^2}\Big[-8A(M_1,M_2) - (M_1^2+M_2^2)b_0(M_1,M_2) + 2a(M_1) + 2a(M_2)\Big] \\
&\quad - \frac{1}{c_w^2 m_Z^2}\left(\frac{1}{2}\right)^2\Big[-8A(M_1,M_1) - 2M_1^2 b_0(M_1,M_1) + 4a(M_1)\Big] \\
&\quad - \frac{1}{c_w^2 m_Z^2}\left(-\frac{1}{2}\right)^2\Big[-8A(M_2,M_2) - 2M_2^2 b_0(M_2,M_2) + 4a(M_2)\Big] \\
&= \frac{1}{m_W^2}\left[M_1^2 + M_2^2 - \frac{2M_1^2 M_2^2}{M_1^2 - M_2^2} \ln\frac{M_1^2}{M_2^2}\right]
\end{aligned}
$$

- Thereby, modify the oblique parameter:

$$\Delta\rho = \alpha \Delta T$$

$$\Delta\rho \equiv \frac{\Pi^T_{WW}(0)}{m_W^2} - \frac{\Pi^T_{ZZ}(0)}{m_Z^2} = \frac{N_C \alpha}{4\pi s_w^2 c_w^2 m_Z^2}\left[M_1^2 + M_2^2 - \frac{2M_1^2 M_2^2}{M_1^2 - M_2^2}\ln\frac{M_1^2}{M_2^2}\right]$$

$$\Delta T = \frac{N_C}{4\pi s_w^2 c_w^2 m_Z^2}\left[M_1^2 + M_2^2 - \frac{2M_1^2 M_2^2}{M_1^2 - M_2^2}\ln\frac{M_1^2}{M_2^2}\right]$$

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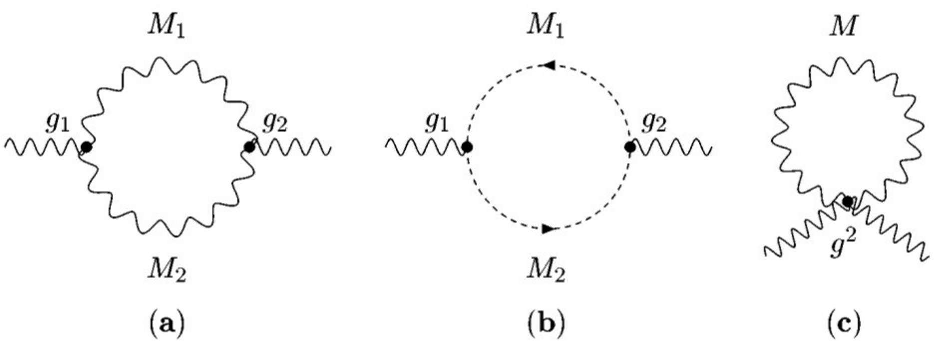

$$
\begin{aligned}
&\left\{\frac{\Pi^T_{WW}(0)}{m_W^2} - \frac{\Pi^T_{ZZ}(0)}{m_Z^2}\bigg|_{V^{+4/3}} - \frac{\Pi^T_{ZZ}(0)}{m_Z^2}\bigg|_{V^{+1/3}}\right\} \bigg/ \frac{g^2}{(4\pi)^2} \\
&= \frac{1}{2m_W^2}\Big[-8A(M_1,M_2) - (M_1^2+M_2^2)b_0(M_1,M_2) + 2a(M_1) + 2a(M_2)\Big] \\
&\quad - \frac{1}{c_w^2 m_Z^2}\left(\frac{1}{2}\right)^2\Big[-8A(M_1,M_1) - 2M_1^2 b_0(M_1,M_1) + 4a(M_1)\Big] \\
&\quad - \frac{1}{c_w^2 m_Z^2}\left(-\frac{1}{2}\right)^2\Big[-8A(M_2,M_2) - 2M_2^2 b_0(M_2,M_2) + 4a(M_2)\Big] \\
&= \frac{1}{m_W^2}\left[M_1^2 + M_2^2 - \frac{2M_1^2 M_2^2}{M_1^2 - M_2^2}\ln\frac{M_1^2}{M_2^2}\right]
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$$

- Thereby, modify the oblique parameter:

Proportional to the mass splitting between the upper and lower component of the doublet

$$\Delta\rho = \alpha \Delta T$$

$$\Delta\rho \equiv \frac{\Pi^T_{WW}(0)}{m_W^2} - \frac{\Pi^T_{ZZ}(0)}{m_Z^2} = \frac{N_C \alpha}{4\pi s_w^2 c_w^2 m_Z^2}\left[M_1^2 + M_2^2 - \frac{2M_1^2 M_2^2}{M_1^2 - M_2^2}\ln\frac{M_1^2}{M_2^2}\right]$$

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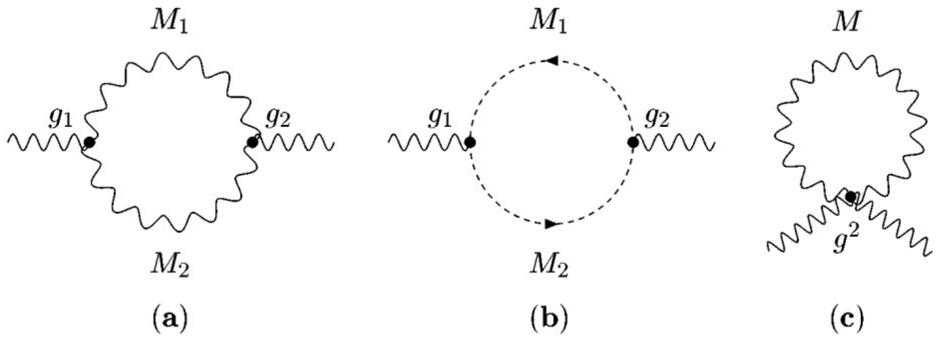
Iso-doublet Vector Leptoquark: V2

- Its gauge interactions contribute to *I) lepton g-2, II)* $\ell_i \to \ell_j \gamma$ *,and III) W boson mass*.
- W mass: V_2 contributions to W/Z vacuum polarizations

Stefan Pokorski, Gauge Field Theory 2nd edition



$$\left\{ \frac{\Pi^T_{WW}(0)}{m_W^2} - \frac{\Pi^T_{ZZ}(0)}{m_Z^2}\Big|_{V^{+4/3}} - \frac{\Pi^T_{ZZ}(0)}{m_Z^2}\Big|_{V^{+1/3}} \right\} \Big/ \frac{g^2}{(4\pi)^2}$$
$$= \frac{1}{2m_W^2}\Big[-8A(M_1, M_2) - (M_1^2 + M_2^2) b_0(M_1, M_2) + 2a(M_1) + 2a(M_2) \Big]$$
$$- \frac{1}{c_w^2 m_Z^2}\left(\frac{1}{2}\right)^2 \Big[-8A(M_1, M_1) - 2M_1^2 b_0(M_1, M_1) + 4a(M_1) \Big]$$
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- Thereby, modify the W boson mass:

$$\Delta M_W^2 = \frac{\alpha c_W^4 M_Z^2}{c_W^2 - s_W^2} \Delta T$$

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- W mass:

K.Cheung, W.Y.Keung, and P.Y Tseng, arXiv: 2204.05942

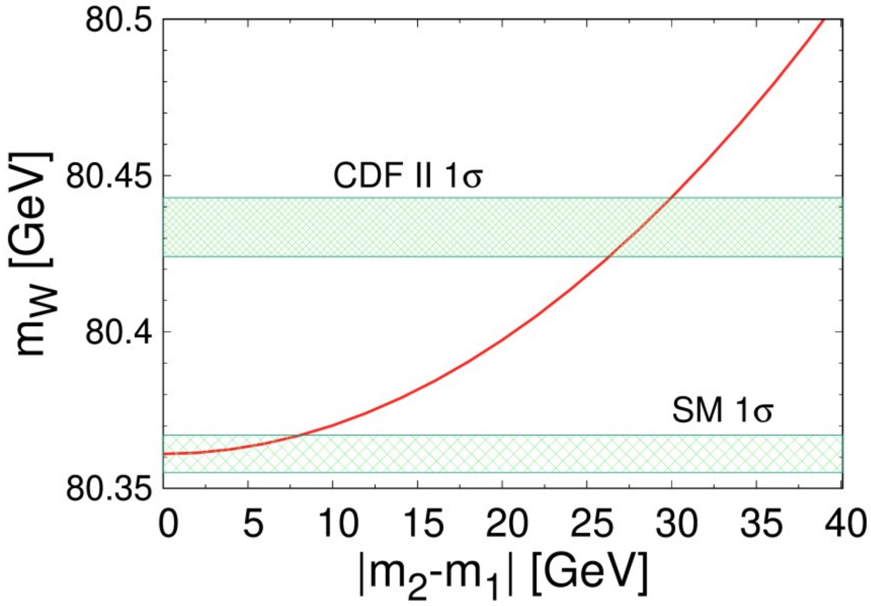

Figure 2. The resulting W-boson mass due to the mass splitting between the upper and lower isospin component of the vector LQ V_2 around 2 TeV. Note that the lower band in green is the SM prediction while the upper band in the latest CDF measurement.

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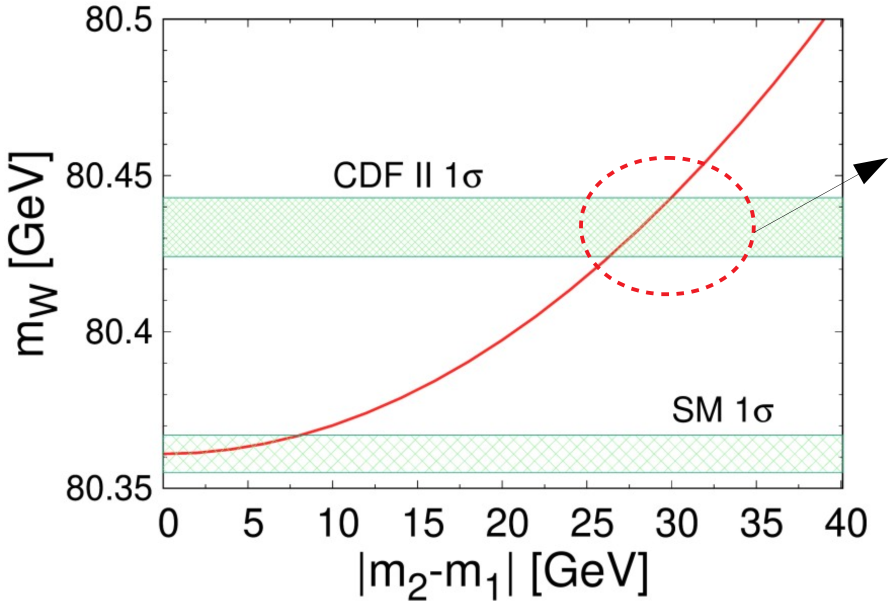

Mass splitting of 25-30 GeV provides a solution to the W-mass anomaly.

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Global fit Results of V2 LQ

- Results of global fitting of B-meson observables:

K.Cheung, W.Y.Keung, and P.Y Tseng, arXiv: 2204.05942

$$\textbf{Scan}: \quad -20 \le X_{21}^{LR} \le 20\,, \quad 0 \le X_{31}^{LR} \le \sqrt{4\pi}\,, \quad -1 \le X_{31}^{RL} \le 1\,,$$
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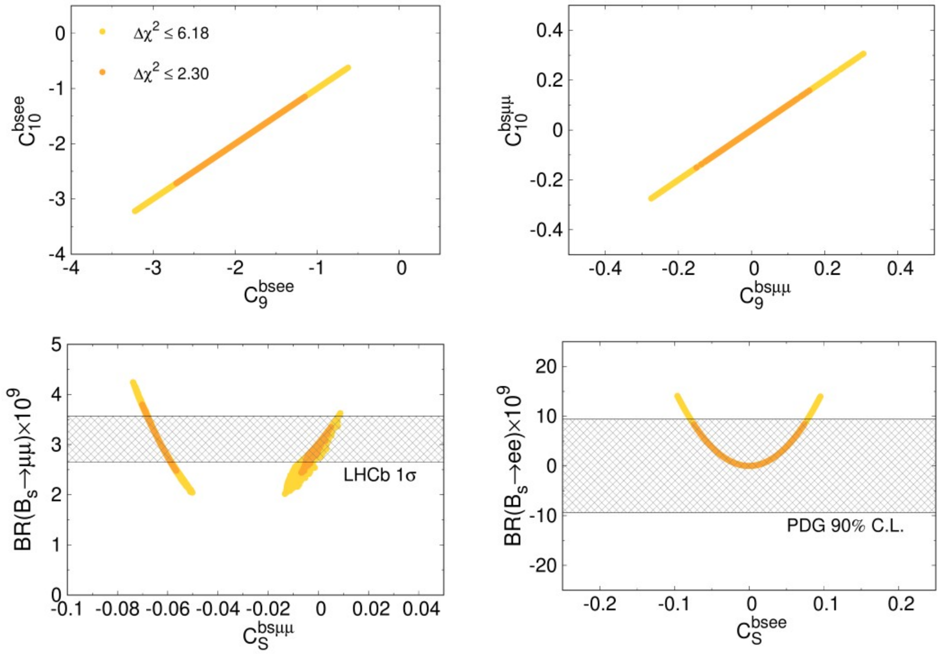
$$-1 \le X_{23}^{LR} \le 1\,, \quad -2 \le X_{33}^{RL} \le 2\,, \quad m_{V_2} = 2\ \text{TeV}\,.$$



Explain the B-meson anomalous by enhance the electron channel. And consistent with constraints from Bs-->l+l-

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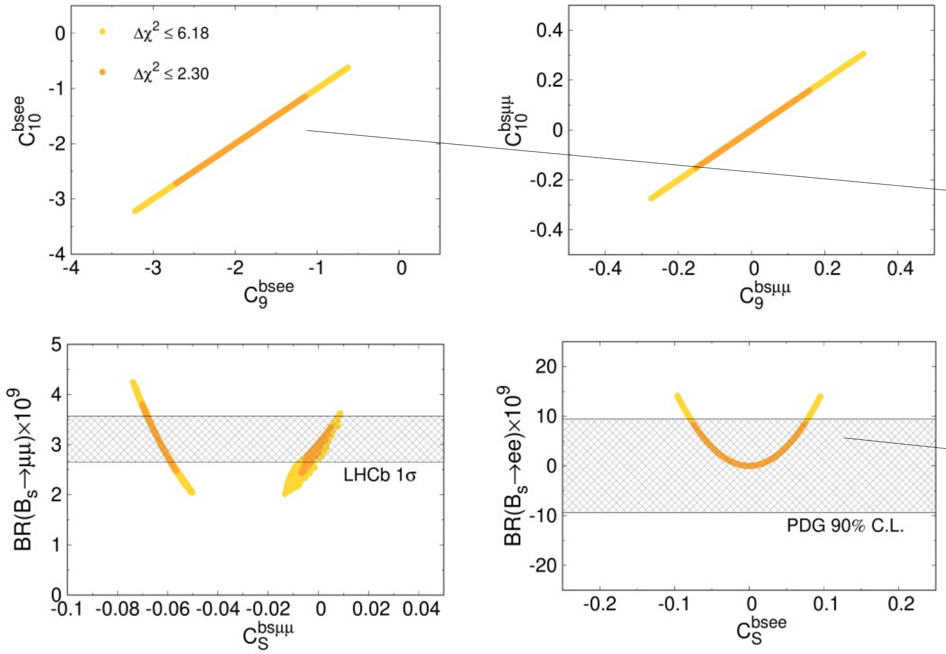

$$\frac{X_{31}^{LR}(X_{21}^{LR})^*}{m_{V_2}^2} \simeq \frac{-0.0030}{(1\text{ TeV})^2}$$

$$\frac{|X_{31}^{RL}(X_{21}^{LR})^*|}{m_{V_2}^2} \lesssim \frac{10^{-4}}{(1\text{ TeV})^2}$$

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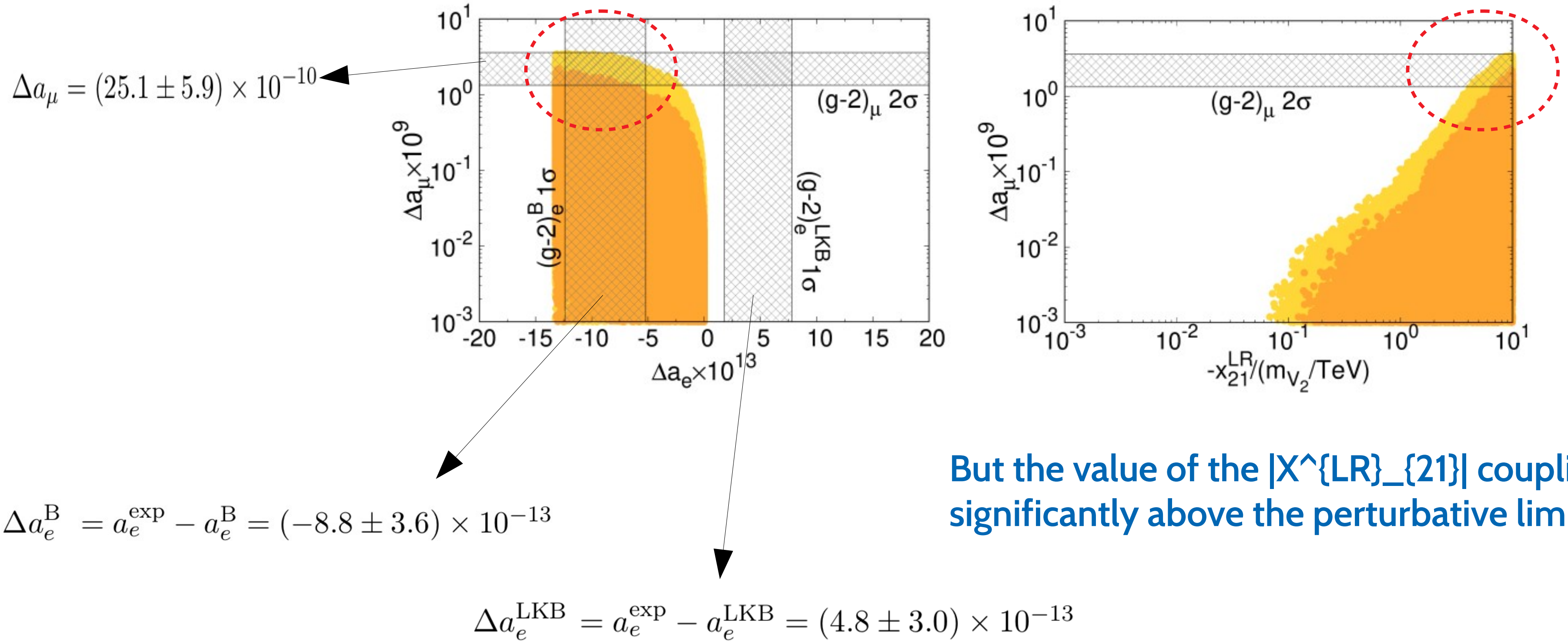

But the value of the |X^{LR}_{21}| coupling is significantly above the perturbative limit.

K.Cheung, W.Y.Keung, and P.Y Tseng, arXiv: 2204.05942

Global fit Results of V2 LQ

- To generate large enough muon g-2, the direct obstacle is

$$B(\mu \to e\gamma) < 4.2 \times 10^{-13}\,, \quad 90\%\ \text{C.L.}$$

$$\boxed{\Gamma(\mu \to e\gamma) = \frac{\alpha_{\rm em}}{4} m_\mu^5 \left(|A_L^{\mu e}|^2 + |A_R^{\mu e}|^2\right)}$$

$$\begin{aligned} A_L^{\ell_i \ell_j} &= -\frac{N_C}{16\pi^2 M_V^2} \sum_k \Big[-2 X_{k\ell_j}^{LR*} X_{k\ell_i}^{RL} \frac{m_k}{m_{\ell_i}} (Q_V + Q_{b^c}) \\ &\quad + \left(X_{k\ell_j}^{LR*} X_{k\ell_i}^{LR} + X_{k\ell_j}^{RL*} X_{k\ell_i}^{RL} \frac{m_{\ell_j}}{m_{\ell_i}} \right) \left(-\frac{5}{6} Q_V - \frac{2}{3} Q_{b^c} \right) \Big] , \\ A_R^{\ell_i \ell_j} &= A_L^{\ell_i \ell_j} (L \leftrightarrow R) \end{aligned}$$

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$$\Delta a_\ell = -\frac{N_C}{16\pi^2} \left[4\mathcal{R}e(X_{3\ell}^{LR*} X_{3\ell}^{RL}) \frac{m_b m_\ell}{M_V^2} (Q_V + Q_{b^c}) + 2(|X_{3\ell}^{LR}|^2 + |X_{3\ell}^{RL}|^2) \frac{m_\ell^2}{M_V^2} \left(\frac{5}{6} Q_V + \frac{2}{3} Q_{b^c} \right) \right]$$

$\to$ $X_{32}^{\rm LR} X_{32}^{\rm RL}$

So suppressing |X^{LR,RL}_{31}| coupling to avoid mu-→e+gamma may help to unleash a large enough muon g-2.

K.Cheung, W.Y.Keung, and P.Y Tseng, arXiv: 2204.05942

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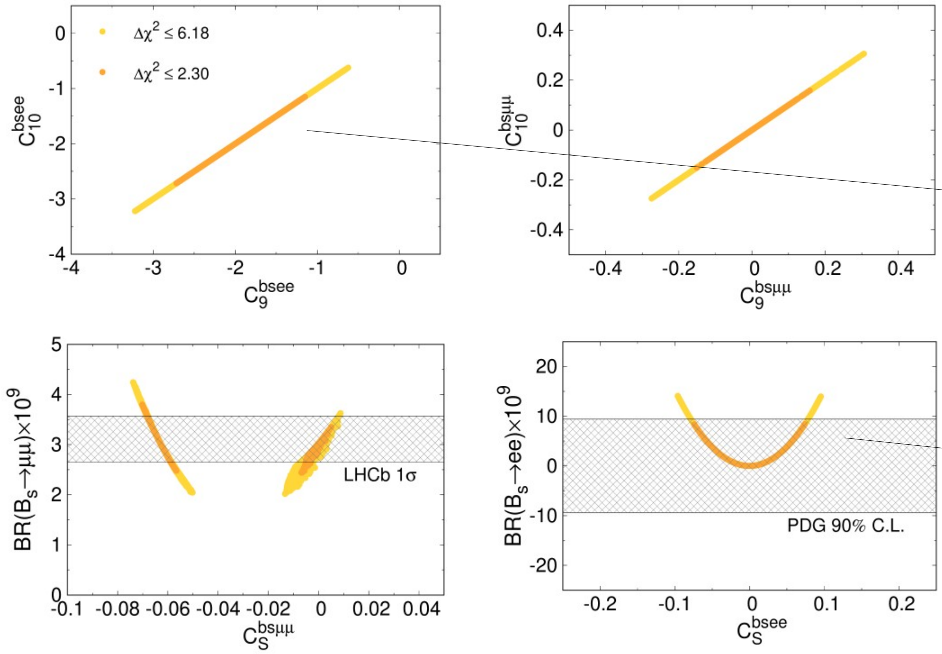

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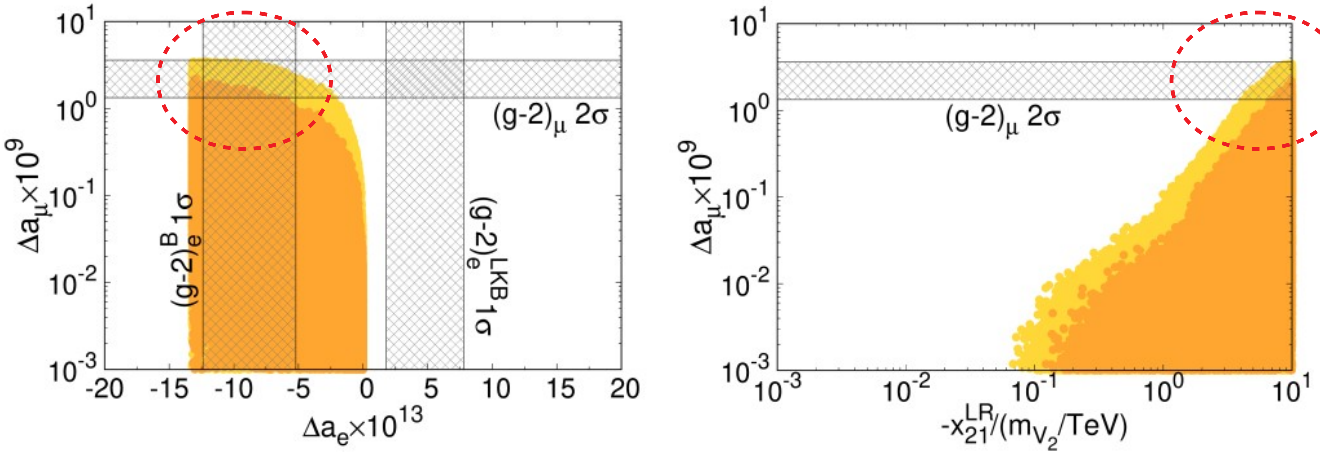

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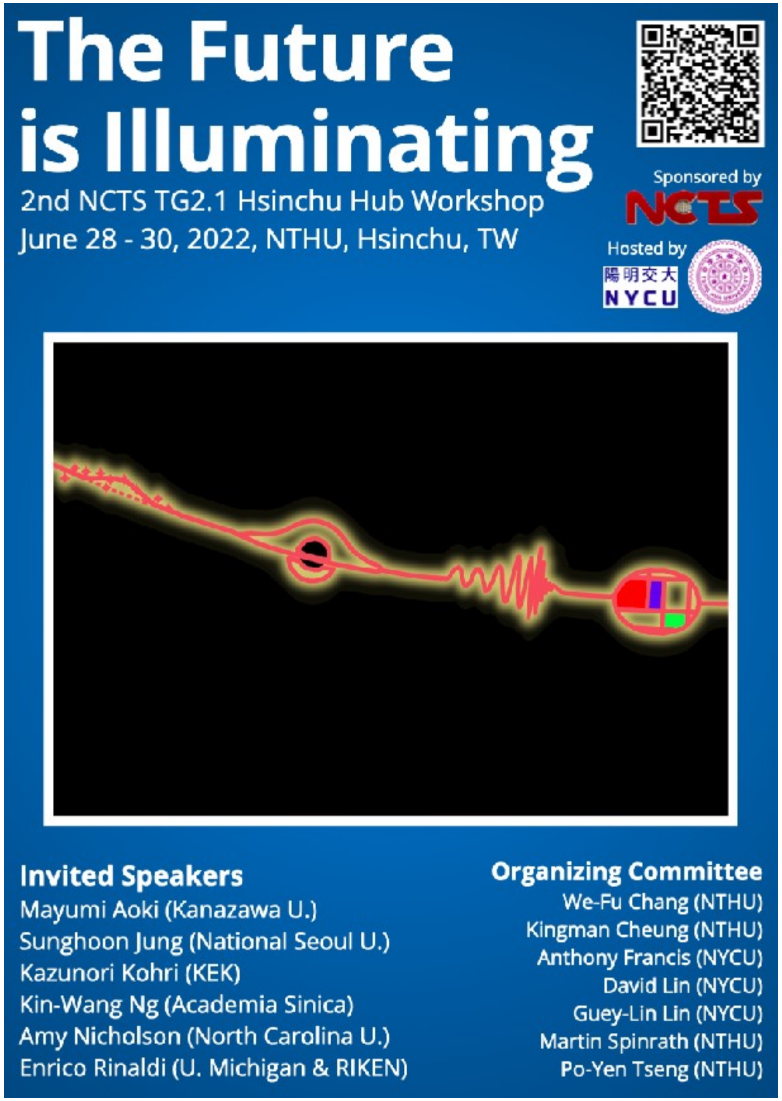
K.Cheung, W.Y.Keung, and P.Y Tseng, arXiv: 2204.05942

Summary

Summary

- We consider iso-doublet vector leptoquark, V2.
- 25-30 GeV mass splitting of 2 TeV LQ raising the W mass to the CDF II result.
- V2 LQ explain B anomalous by increasing the $B \to K e^+ e^-$.
- Here, we investigate to find common solution for muon g-2, but the coupling $|X_{21}^{\rm LR}|$ is beyond the *perturbative limit*.

NCTS workshop by NYCU/NTHU:
The Future is Illuminating (28-30 June)



Topics:

1. DM and Physics BSM
2. Primordial Black Holes
3. Gravitational Waves and their Detectors
4. Lattice Quantum Chromodynamics

Registration deadline is 10th June.

Thank you for your attention!