河南省科学院
HENAN ACADEMY OF SCIENCES

復旦大學

Revisiting Vacuum Stability and CEPC Constraints on the Georgi-Machacek Model

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8/18/2023

Based on Xk Du, Zhuang Li, Fei Wang, Yingkai Zhang, 2204.05760;
Xk Du, Fei Wang, 2308.****

2023年8月18日 @ CEPC味物理-新物理和相关探测技术研讨会

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1、 Introduction to the Georgi-Machacek Model

The Georgi-Machacek Model

$$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}, \qquad \chi = \begin{pmatrix} \chi^{++} \\ \chi^+ \\ \chi^0 \end{pmatrix}, \qquad \xi = \begin{pmatrix} \xi^+ \\ \xi^0 \\ \xi^- \end{pmatrix}$$

Fields	$U(1)_Y$	$SU(2)_L$	$SU(3)_C$
ϕ	1/2	2	1
χ	1	3	1
ξ	0	3	1

$$\xrightarrow{SU(2)_L\times SU(2)_R}$$

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^+ \\ \phi^- & \phi^0 \end{pmatrix}, \Delta = \begin{pmatrix} \chi^{0*} & \xi^+ & \chi^{++} \\ \chi^- & \xi^0 & \chi^+ \\ \chi^{--} & \xi^- & \chi^0 \end{pmatrix}$$

$$\mathcal{L}_{GM} = \mathcal{L}_{kin} + \mathcal{L}_Y + \mathcal{L}_\nu - V_H$$

$$\begin{aligned} V(\Phi,\Delta) = {} & \frac{1}{2}\mathrm{m}_\Phi^2\mathrm{Tr}[\Phi^\dagger\Phi] + \frac{1}{2}\mathrm{m}_\Delta^2\mathrm{Tr}[\Delta^\dagger\Delta] \\ & + \lambda_1\left(\mathrm{Tr}[\Phi^\dagger\Phi]\right)^2 + \lambda_2\left(\mathrm{Tr}[\Delta^\dagger\Delta]\right)^2 \\ & + \lambda_3\mathrm{Tr}\left[\left(\Delta^\dagger\Delta\right)^2\right] + \lambda_4\mathrm{Tr}[\Phi^\dagger\Phi]\mathrm{Tr}[\Delta^\dagger\Delta] \\ & + \lambda_5\mathrm{Tr}\left[\Phi^\dagger\frac{\sigma^a}{2}\Phi\frac{\sigma^b}{2}\right]\mathrm{Tr}[\Delta^\dagger T^a\Delta T^b] \\ & + \mu_1\mathrm{Tr}\left[\Phi^\dagger\frac{\sigma^a}{2}\Phi\frac{\sigma^b}{2}\right]\left(P^\dagger\Delta P\right)_{ab} \\ & + \mu_2\mathrm{Tr}[\Delta^\dagger T^a\Delta T^b]\left(P^\dagger\Delta P\right)_{ab} \end{aligned}$$

$$\mathcal{L}_\nu \supset h_{ij}\overline{L_L^{ic}}i\tau_2\chi L_L^j + h.c.$$

Nucl.Phys.B 262 (1985) 463-477，JHEP 01 (2013) 026, JHEP 01 (2016) 120

1、 Introduction to the Georgi-Machacek Model

$$\boxed{SU(2)_L \times SU(2)_R} \xrightarrow[\langle\chi^0\rangle = \langle\xi^0\rangle = v_\Delta]{\langle\phi^0\rangle = v_\phi/\sqrt{2}} \boxed{SU(2)_V}$$

$$v_{EW}^2 = \sum_i \left[4T_i(T_i+1) - Y_i^2\right] |v_i|^2 c_i = v_\phi^2 + 4v_\chi^2 + 4v_\xi^2 = v_\phi^2 + 8v_\Delta^2 = \frac{1}{\sqrt{2}G_F} \approx (246\mathrm{GeV})^2$$

$$c_{T,Y} = \begin{cases} 1\,,(T,Y) \in complex\ representation \\ 1/2\,,(T,Y=0) \in real\ representation \end{cases}$$

$$\rho_{tree} \equiv \frac{m_W^2}{m_Z^2 \cos^2\theta_W} = \sum_i \left[4T_i(T_i+1) - Y_i^2\right] |v_i|^2 c_i \,/ \sum_i 2Y_i|v_i|^2$$

$$\Delta\rho_{tree} \equiv \rho - 1 = \frac{v_\phi^2 + 4v_\chi^2 + 4v_\xi^2}{v_\phi^2 + 8v_\Delta^2} - 1 \approx \frac{4v_\chi^2 - 4v_\xi^2}{v_{EW}^2}$$

$$\tan\theta = 2\sqrt{2}v_\Delta/v_\phi$$

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2、Improved the Vacuum Stability Constraint on the GM Model

Vacuum stability

$$V(\Phi,\Delta)=\frac{1}{2}\mathrm{m}_{\Phi}^{2}\mathrm{Tr}\left[\Phi^{\dagger}\Phi\right]+\frac{1}{2}\mathrm{m}_{\Delta}^{2}\mathrm{Tr}\left[\Delta^{\dagger}\Delta\right]+\lambda_1\left(\mathrm{Tr}\left[\Phi^{\dagger}\Phi\right]\right)^2+\lambda_2\left(\mathrm{Tr}\left[\Delta^{\dagger}\Delta\right]\right)^2$$

$$+\lambda_3\mathrm{Tr}\left[\left(\Delta^{\dagger}\Delta\right)^2\right]+\lambda_4\mathrm{Tr}\left[\Phi^{\dagger}\Phi\right]\mathrm{Tr}\left[\Delta^{\dagger}\Delta\right]+\lambda_5\mathrm{Tr}\left[\Phi^{\dagger}\frac{\sigma^a}{2}\Phi\frac{\sigma^b}{2}\right]\mathrm{Tr}\left[\Delta^{\dagger}T^a\Delta T^b\right]$$

$$+\mu_1\mathrm{Tr}\left[\Phi^{\dagger}\frac{\sigma^a}{2}\Phi\frac{\sigma^b}{2}\right]\left(P^{\dagger}\Delta P\right)_{ab}+\mu_2\mathrm{Tr}\left[\Delta^{\dagger}T^a\Delta T^b\right]\left(P^{\dagger}\Delta P\right)_{ab}$$

$$\boxed{Z_2\ ?}$$

$$r\equiv\sqrt{\mathrm{Tr}[\Phi^{\dagger}\Phi]+\mathrm{Tr}[\Delta^{\dagger}\Delta]},\qquad r^2\cos^2\gamma\equiv\mathrm{Tr}\left[\Phi^{\dagger}\Phi\right],\qquad r^2\sin^2\gamma\equiv\mathrm{Tr}\left[\Delta^{\dagger}\Delta\right],$$

$$\zeta\equiv\frac{\mathrm{Tr}\left[\left(\Delta^{\dagger}\Delta\right)^2\right]}{(\mathrm{Tr}[\Delta^{\dagger}\Delta])^2},\qquad \omega\equiv\frac{\mathrm{Tr}\left[\Phi^{\dagger}\frac{\sigma^a}{2}\Phi\frac{\sigma^b}{2}\right]\mathrm{Tr}\left[\Delta^{\dagger}T^a\Delta T^b\right]}{\mathrm{Tr}[\Phi^{\dagger}\Phi]\mathrm{Tr}[\Delta^{\dagger}\Delta]}.$$

$$r\in[0,\infty),\qquad \gamma\in\left[0,\frac{\pi}{2}\right],\qquad \zeta\in\left[\frac{1}{3},1\right],\qquad \omega\in\left[-\frac{1}{4},\frac{1}{2}\right].$$

$$V(r,\tan\gamma,\zeta,\omega)=\frac{r^4}{(1+\tan^2\gamma)^2}\left[\lambda_1+(\lambda_4-\omega\lambda_5)\tan^2\gamma+(\zeta\lambda_3+\lambda_2)\tan^4\gamma\right]$$

arXiv:1105.1925, 1404.2640, JHEP 01 (2016) 120

2、Improved the Vacuum Stability Constraint on the GM Model

Vacuum stability

$$\lambda_1 > 0,$$

$$\lambda_2 > \begin{cases} -\frac{1}{3}\lambda_3 \;\; for\; \lambda_3 \geq 0, \\ -\lambda_3 \quad for\; \lambda_3 < 0, \end{cases}$$

$$\lambda_4 > \begin{cases} \frac{1}{2}\lambda_5 - 2\sqrt{\lambda_1\left(\frac{1}{3}\lambda_3 + \lambda_2\right)} \quad for\; \lambda_5 \geq 0\; and\; \lambda_3 \geq 0, \\ \omega_+(\zeta)\lambda_5 - 2\sqrt{\lambda_1(\lambda_3 + \lambda_2)} \quad for\; \lambda_5 \geq 0\; and\; \lambda_3 < 0 \\ \omega_-(\zeta)\lambda_5 - 2\sqrt{\lambda_1(\lambda_3 + \lambda_2)}.\; for\; \lambda_5 < 0 \end{cases}$$

$$\lambda_1 > 0,$$

$$\lambda_2 + \lambda_3 > 0,$$

$$\lambda_2 + \frac{1}{2}\lambda_3 > 0,$$

$$-|\lambda_4| + 2\sqrt{\lambda_1(\lambda_2 + \lambda_3)} > 0,$$

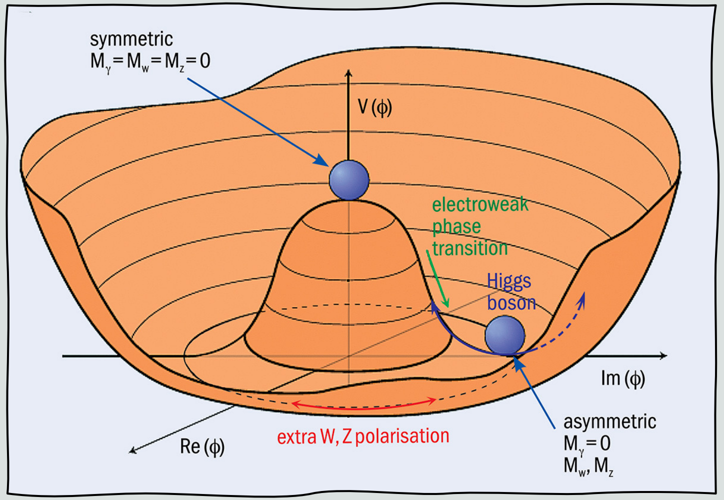
$$\lambda_4 - \frac{1}{4}|\lambda_5| + \sqrt{2\lambda_1(2\lambda_2 + \lambda_3)} > 0.$$

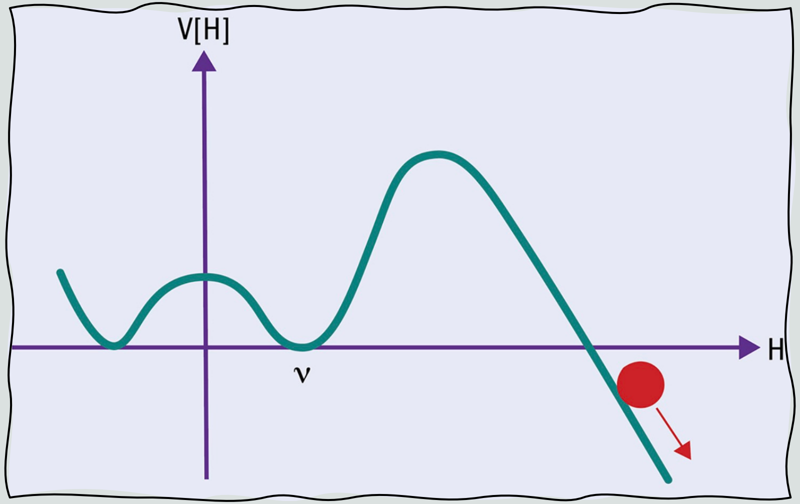
Cheng-Wei Chiang etc, 1211.2658, 1511.00865

$$\omega_\pm(\zeta) = \frac{1}{6}(1-B) \pm \frac{\sqrt{2}}{3}\left[(1-B)\left(\frac{1}{2} + B\right)\right]^{1/2}, \qquad B \equiv \sqrt{\frac{3}{2}\left(\zeta - \frac{1}{3}\right)} \in [0,1], \qquad \zeta \in \left[\frac{1}{3}, 1\right].$$

Logan etc, arXiv:1404.2640, JHEP 01 (2016) 120

2、Improved the Vacuum Stability Constraint on the GM Model





Credit: J Ellis/M Neubauer

Large field approximation ↔ High energy scale approximation ↔ RGE

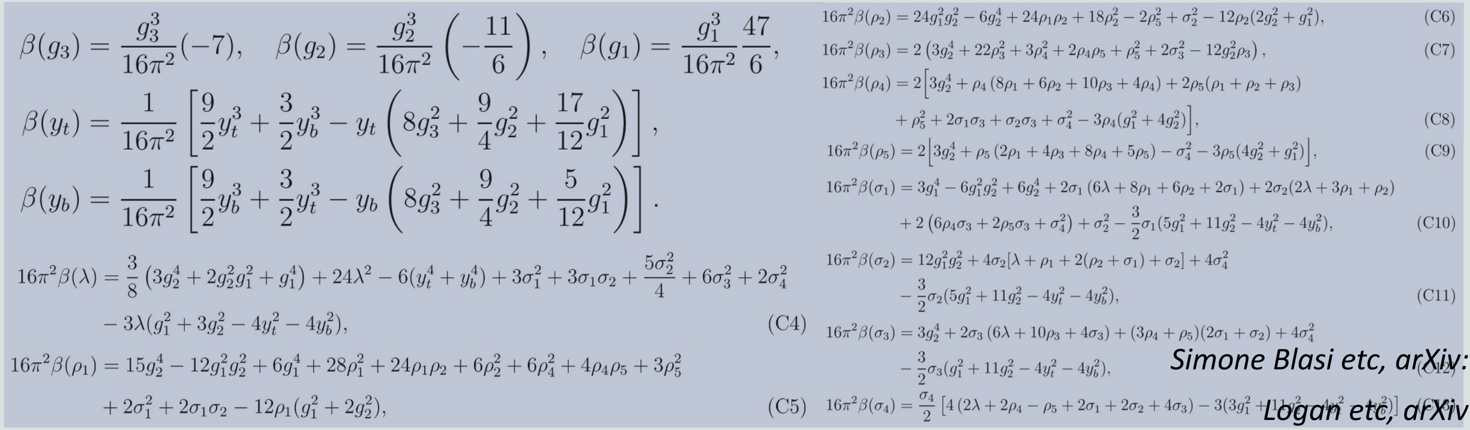
2、Improved the Vacuum Stability Constraint on the GM Model

$SU(2)_L$
×
$U(1)_Y$

$$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}, \qquad \chi = \begin{pmatrix} \chi^+/\sqrt{2} & -\chi^{++} \\ \chi^0 & -\chi^+/\sqrt{2} \end{pmatrix}, \qquad \xi = \begin{pmatrix} \xi^0/\sqrt{2} & -\xi^+ \\ -\xi^- & -\xi^0/\sqrt{2} \end{pmatrix}$$

$$\begin{aligned} V(\phi,\chi,\xi) = {} & m_\phi^2(\phi^\dagger\phi) + m_\chi^2(\chi^\dagger\chi) + m_\xi^2(\xi^\dagger\xi) + \lambda(\phi^\dagger\phi)^2 \\ & + \rho_1\left(\mathrm{Tr}[\chi^\dagger\chi]\right)^2 + \rho_2\mathrm{Tr}[\chi^\dagger\chi\chi^\dagger\chi] + \rho_3\mathrm{Tr}[\xi^4] \\ & + \rho_4\mathrm{Tr}[\chi^\dagger\chi]\mathrm{Tr}[\xi^2] + \rho_5\mathrm{Tr}[\chi^\dagger\xi]\mathrm{Tr}[\xi\chi] + \sigma_1\mathrm{Tr}[\chi^\dagger\chi]\phi^\dagger\phi \\ & + \sigma_2\phi^\dagger\chi\chi^\dagger\phi + \sigma_3\mathrm{Tr}[\xi^2]\phi^\dagger\phi + \sigma_4\left(\phi^\dagger\chi\zeta\phi^c + \mathrm{h.c.}\right) \end{aligned}$$

$$\beta(X) \equiv \frac{d}{d\ln\mu}X$$



$$\beta(g_3) = \frac{g_3^3}{16\pi^2}(-7), \quad \beta(g_2) = \frac{g_2^3}{16\pi^2}\left(-\frac{11}{6}\right), \quad \beta(g_1) = \frac{g_1^3}{16\pi^2}\frac{47}{6},$$

$$\beta(y_t) = \frac{1}{16\pi^2}\left[\frac{9}{2}y_t^3 + \frac{3}{2}y_b^3 - y_t\left(8g_3^2 + \frac{9}{4}g_2^2 + \frac{17}{12}g_1^2\right)\right],$$

$$\beta(y_b) = \frac{1}{16\pi^2}\left[\frac{9}{2}y_b^3 + \frac{3}{2}y_t^3 - y_b\left(8g_3^2 + \frac{9}{4}g_2^2 + \frac{5}{12}g_1^2\right)\right].$$

$$\begin{aligned} 16\pi^2\beta(\lambda) = {} & \frac{3}{8}\left(3g_2^4 + 2g_2^2g_1^2 + g_1^4\right) + 24\lambda^2 - 6(y_t^4 + y_b^4) + 3\sigma_1^2 + 3\sigma_1\sigma_2 + \frac{5\sigma_2^2}{4} + 6\sigma_3^2 + 2\sigma_4^2 \\ & - 3\lambda(g_1^2 + 3g_2^2 - 4y_t^2 - 4y_b^2), \end{aligned} \quad \text{(C4)}$$

$$\begin{aligned} 16\pi^2\beta(\rho_1) = {} & 15g_2^4 - 12g_1^2g_2^2 + 6g_1^4 + 28\rho_1^2 + 24\rho_1\rho_2 + 6\rho_2^2 + 6\rho_4^2 + 4\rho_4\rho_5 + 3\rho_5^2 \\ & + 2\sigma_1^2 + 2\sigma_1\sigma_2 - 12\rho_1(g_1^2 + 2g_2^2), \end{aligned} \quad \text{(C5)}$$

$$16\pi^2\beta(\rho_2) = 24g_1^2g_2^2 - 6g_2^4 + 24\rho_1\rho_2 + 18\rho_2^2 - 2\rho_5^2 + \sigma_2^2 - 12\rho_2(2g_2^2 + g_1^2), \quad \text{(C6)}$$

$$16\pi^2\beta(\rho_3) = 2\left(3g_2^4 + 22\rho_3^2 + 3\rho_4^2 + 2\rho_4\rho_5 + \rho_5^2 + 2\sigma_3^2 - 12g_2^2\rho_3\right), \quad \text{(C7)}$$

$$\begin{aligned} 16\pi^2\beta(\rho_4) = 2\Big[& 3g_2^4 + \rho_4\left(8\rho_1 + 6\rho_2 + 10\rho_3 + 4\rho_4\right) + 2\rho_5(\rho_1 + \rho_2 + \rho_3) \\ & + \rho_5^2 + 2\sigma_1\sigma_3 + \sigma_2\sigma_3 + \sigma_4^2 - 3\rho_4(g_1^2 + 4g_2^2)\Big], \end{aligned} \quad \text{(C8)}$$

$$16\pi^2\beta(\rho_5) = 2\Big[3g_2^4 + \rho_5\left(2\rho_1 + 4\rho_3 + 8\rho_4 + 5\rho_5\right) - \sigma_4^2 - 3\rho_5(4g_2^2 + g_1^2)\Big], \quad \text{(C9)}$$

$$\begin{aligned} 16\pi^2\beta(\sigma_1) = {} & 3g_1^4 - 6g_1^2g_2^2 + 6g_2^4 + 2\sigma_1\left(6\lambda + 8\rho_1 + 6\rho_2 + 2\sigma_1\right) + 2\sigma_2(2\lambda + 3\rho_1 + \rho_2) \\ & + 2\left(6\rho_4\sigma_3 + 2\rho_5\sigma_3 + \sigma_4^2\right) + \sigma_2^2 - \frac{3}{2}\sigma_1(5g_1^2 + 11g_2^2 - 4y_t^2 - 4y_b^2), \end{aligned} \quad \text{(C10)}$$

$$\begin{aligned} 16\pi^2\beta(\sigma_2) = {} & 12g_1^2g_2^2 + 4\sigma_2[\lambda + \rho_1 + 2(\rho_2 + \sigma_1) + \sigma_2] + 4\sigma_4^2 \\ & - \frac{3}{2}\sigma_2(5g_1^2 + 11g_2^2 - 4y_t^2 - 4y_b^2), \end{aligned} \quad \text{(C11)}$$

$$\begin{aligned} 16\pi^2\beta(\sigma_3) = {} & 3g_2^4 + 2\sigma_3\left(6\lambda + 10\rho_3 + 4\sigma_3\right) + (3\rho_4 + \rho_5)(2\sigma_1 + \sigma_2) + 4\sigma_4^2 \\ & - \frac{3}{2}\sigma_3(g_1^2 + 11g_2^2 - 4y_t^2 - 4y_b^2), \end{aligned} \quad \text{(C12)}$$

$$16\pi^2\beta(\sigma_4) = \frac{\sigma_4}{2}\left[4\left(2\lambda + 2\rho_4 - \rho_5 + 2\sigma_1 + 2\sigma_2 + 4\sigma_3\right) - 3(3g_1^2 + 11g_2^2 - 4y_t^2 - 4y_b^2)\right] \quad \text{(C13)}$$

Simone Blasi etc, arXiv:1704.08512,
Logan etc, arXiv:1807.11511

2、Improved the Vacuum Stability Constraint on the GM Model

$$V(\phi,\chi,\xi) = m_\phi^2(\phi^\dagger\phi) + m_\chi^2(\chi^\dagger\chi) + m_\xi^2(\xi^\dagger\xi) + \lambda(\phi^\dagger\phi)^2$$
$$+\rho_1(\mathrm{Tr}[\chi^\dagger\chi])^2 + \rho_2\mathrm{Tr}[\chi^\dagger\chi\chi^\dagger\chi] + \rho_3\mathrm{Tr}[\xi^4]$$
$$+\rho_4\mathrm{Tr}[\chi^\dagger\chi]\mathrm{Tr}[\xi^2] + \rho_5\mathrm{Tr}[\chi^\dagger\xi]\mathrm{Tr}[\xi\chi] + \sigma_1\mathrm{Tr}[\chi^\dagger\chi]\phi^\dagger\phi$$
$$+\sigma_2\phi^\dagger\chi\chi^\dagger\phi + \sigma_3\mathrm{Tr}[\xi^2]\phi^\dagger\phi + \sigma_4(\phi^\dagger\chi\zeta\phi^c + \mathrm{h.c.})$$

$SU(2)_V$
Limit

$$m_\phi^2 = 2m_\Phi^2, m_\chi^2 = 2m_\Delta^2, m_\zeta^2 = m_\Delta^2, \mu_1 = -\frac{\bar{\mu}_1}{\sqrt{2}}, \mu_2 = -\frac{\bar{\mu}_1}{\sqrt{2}},$$
$$\mu_3 = 6\sqrt{2}\bar{\mu}_2, \lambda = 4\lambda_1, \rho_1 = 4\lambda_4 + 6\lambda_3, \rho_2 = -4\lambda_3, \rho_3 = 2(\lambda_4 + \lambda_3),$$
$$\rho_4 = 4\lambda_4, \rho_5 = 4\lambda_3, \sigma_1 = 4\lambda_2 - \lambda_5, \sigma_2 = 2\lambda_5, \sigma_3 = 2\lambda_2, \sigma_4 = \sqrt{2}\lambda_5.$$

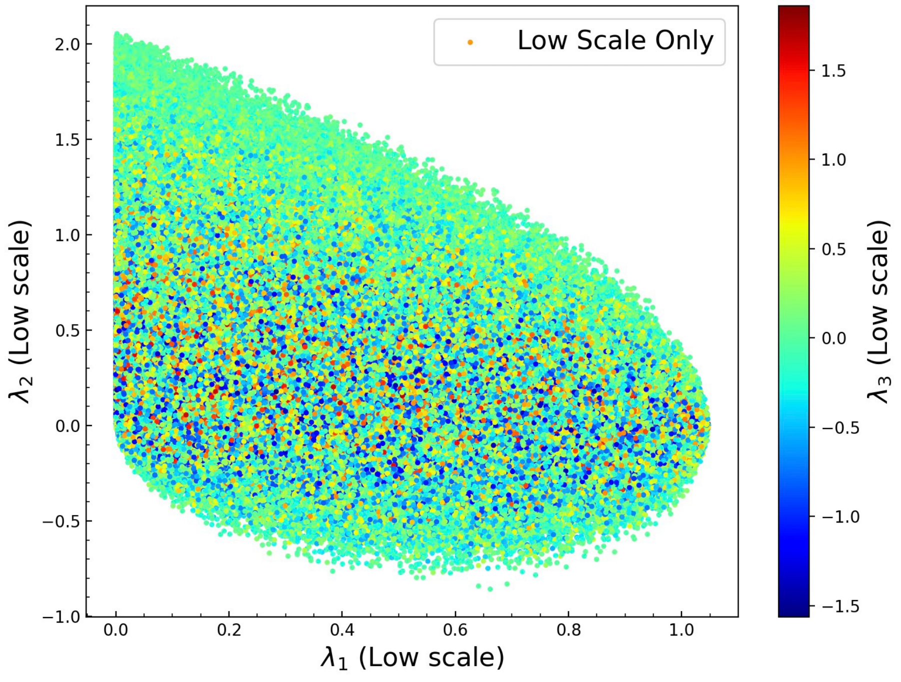
$$m_\chi^2 = 2m_\zeta^2, \qquad \mu_1 = \sqrt{2}\,\mu_2,$$
$$\rho_3 = \frac{1}{2}\rho_1 + \frac{1}{4}\rho_2,\ \rho_4 = \rho_1 + \frac{3}{2}\rho_2,\ \rho_5 = -2\rho_2$$
$$\sigma_3 = \frac{1}{2}\sigma_1 + \frac{1}{4}\sigma_2, \qquad \sigma_4 = \frac{1}{\sqrt{2}}\sigma_2.$$

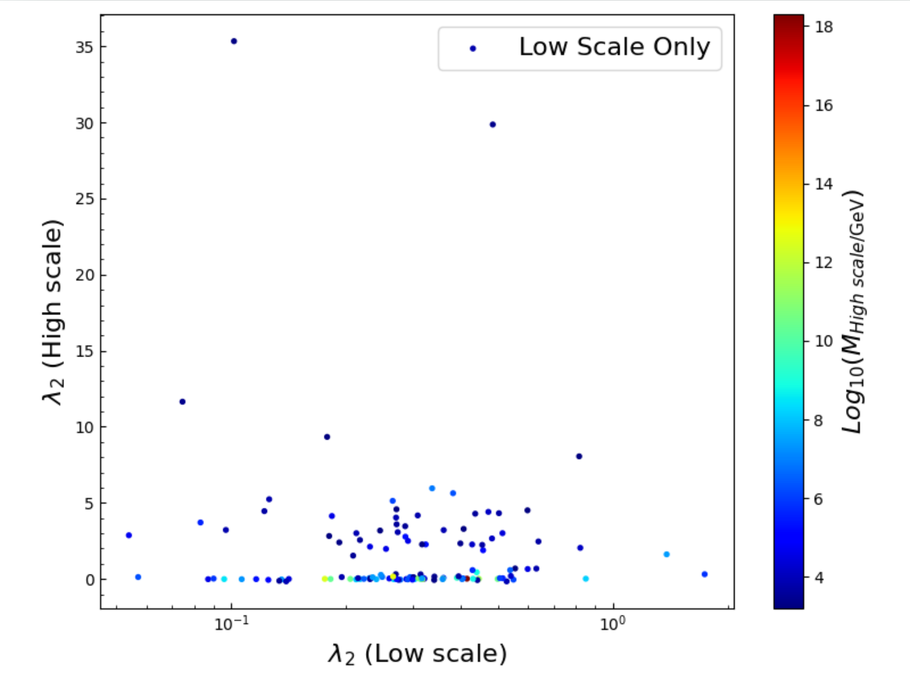
$$\delta_m^2 = m_\chi^2 - 2m_\zeta^2, \qquad \delta_\mu = \mu_1 - \sqrt{2}\,\mu_2,$$
$$\delta_\rho^1 = \rho_3 - \frac{1}{2}\rho_1 - \frac{1}{4}\rho_2, \qquad \dots\dots$$
$$\delta_\sigma^1 = \sigma_3 - \frac{1}{2}\sigma_1 - \frac{1}{4}\sigma_2, \qquad \dots\dots$$

Simone Blasi et al, arXiv:1704.08512

2、Improved the Vacuum Stability Constraint on the GM Model

Low: ✓ **High:** ✗

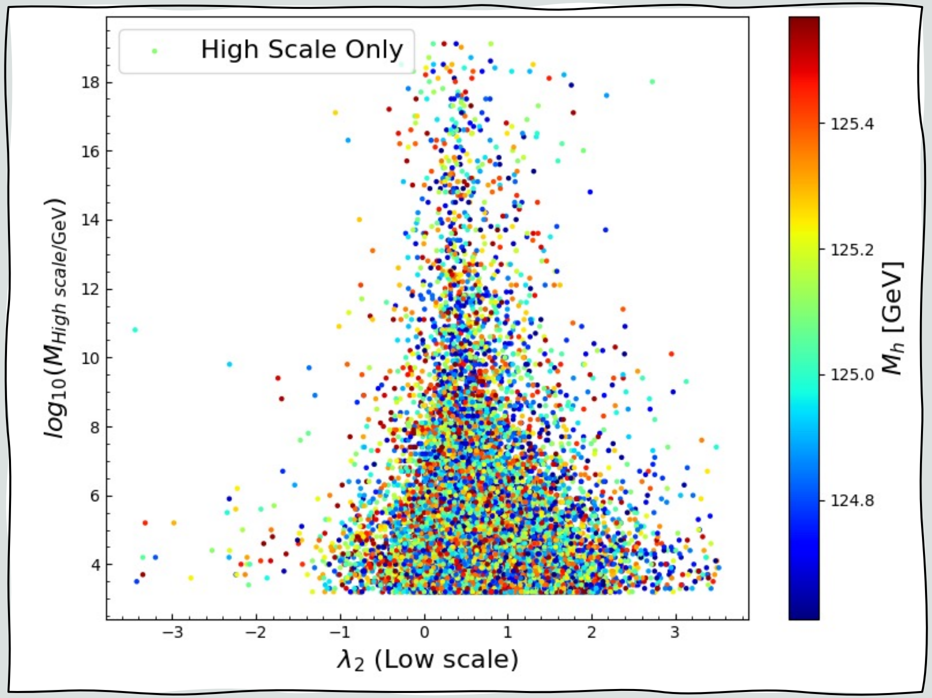


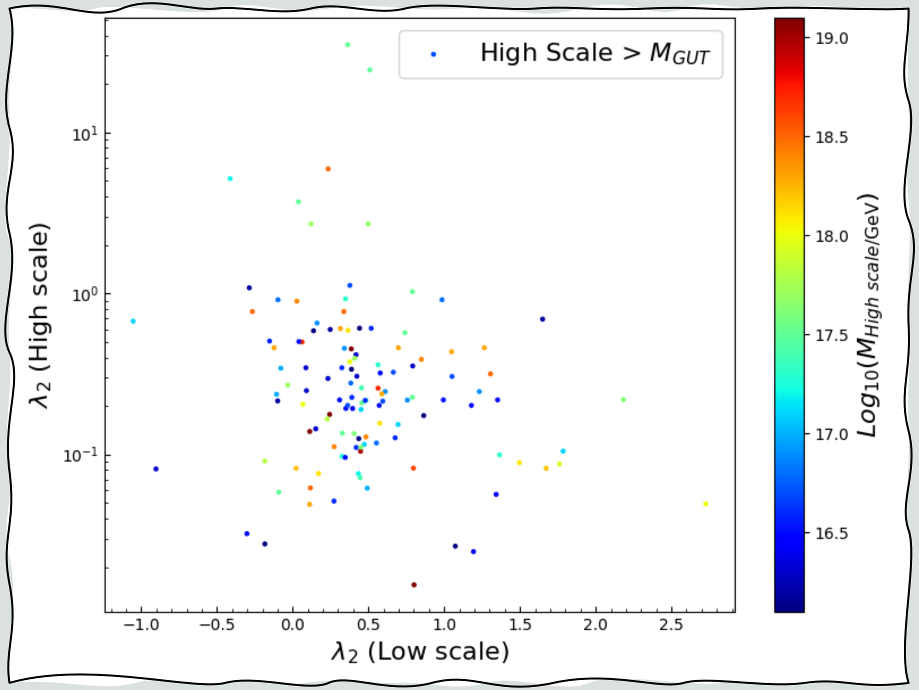


2、Improved the Vacuum Stability Constraint on the GM Model

High energy scale : ✓

Low energy scale : ✗

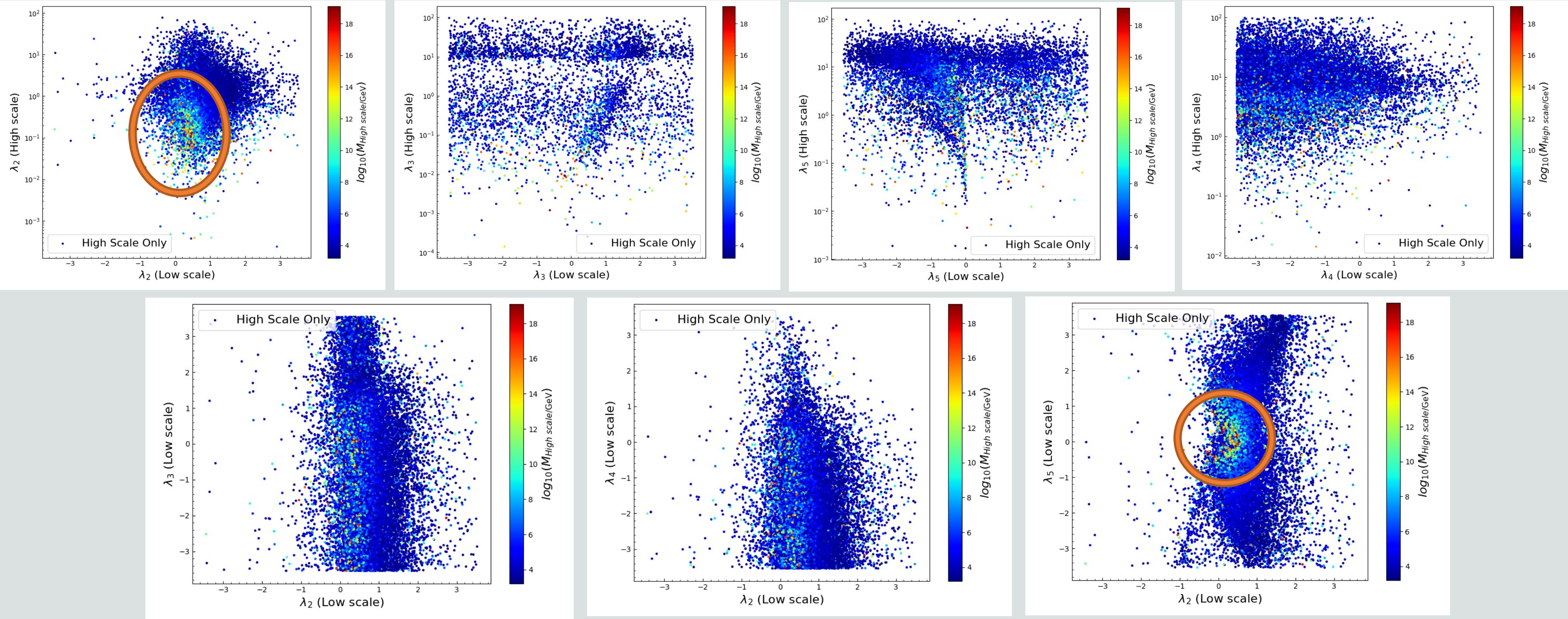




2、Improved the Vacuum Stability Constraint on the GM Model

High energy scale : ✓

Low energy scale : ✗



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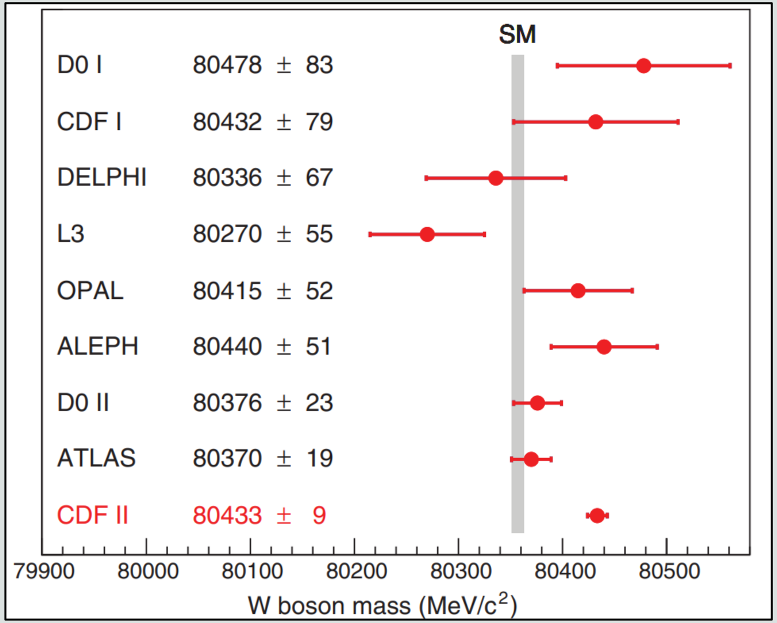
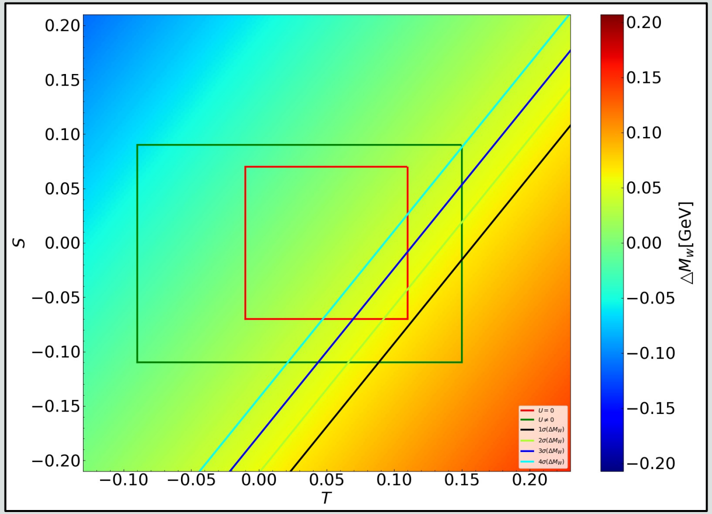
3、W-Boson Mass and CEPC constraints on the the GM Model

CDF-II Results on W Boson Mass





$$S = 0.00 \pm 0.07,$$
$$T = 0.05 \pm 0.06,$$
$$U = 0$$

$$S = -0.01 \pm 0.10,$$
$$T = 0.03 \pm 0.012,$$
$$U = 0.02 \pm 0.11$$

Phys. Rev. D 46 (1992) 381,

PTEP 2020 (2020) 8, 083C01

SM: $M_W = 80357 \pm 6$ MeV

CDF-II: $M_W = 80433.5 \pm 9.4$ MeV

Science 376, 170-176 (2022)

$$\Delta m_W = \frac{\alpha M_W}{2(c_W^2 - s_W^2)}\left(-\frac{1}{2}S + c_W^2 T + \frac{c_W^2 - s_W^2}{4s_W^2}U\right),$$

$$\alpha S = 4s_W^2 c_W^2\left[\Pi'_{ZZ}(0) - \frac{c_W^2 - s_W^2}{s_W c_W}\Pi'_{Z\gamma}(0) - \Pi'_{\gamma\gamma}(0)\right],$$

$$\alpha T = \frac{\Pi_{WW}(0)}{m_W^2} - \frac{\Pi_{ZZ}(0)}{m_Z^2},$$

$$\alpha U = 4s_W^2\left[\Pi'_{WW}(0) - c_W^2\Pi'_{ZZ}(0) - 2s_W c_W\Pi'_{Z\gamma}(0) - s_W^2\Pi'_{\gamma\gamma}(0)\right]$$

3、W-Boson Mass and CEPC constraints on the the GM Model

$$\mathcal{L}_{type-II} \supset h_{ij}\overline{L_L^{ic}}i\tau_2\chi L_L^j + \mu_1 \mathrm{tr}\left[\Phi^\dagger \frac{\sigma^a}{2}\Phi\frac{\sigma^b}{2}\right](P^\dagger\Delta P)_{ab}$$

$$\boldsymbol{SU(2)_L \times SU(2)_R} \xrightarrow[\langle\chi^0\rangle = \langle\xi^0\rangle = v_\Delta]{\langle\phi^0\rangle = v_\phi/\sqrt{2}} \boldsymbol{SU(2)_V}$$

$$m_\nu \approx h_{ij}v_\Delta \sim h_{ij}v_\phi^2\mu_1/m_\Delta^2$$

$$\tan\theta = 2\sqrt{2}v_\Delta/v_\phi < 0.4$$

$$v_\Delta \sim \mathcal{O}(10\mathrm{GeV}) \Rightarrow h_{ij} < 10^{-13}$$

Vacuum stability

$$\lambda_1 > 0, \lambda_2 + \lambda_3 > 0, \lambda_2 + \frac{1}{2}\lambda_3 > 0,$$
$$-|\lambda_4| + 2\sqrt{\lambda_1(\lambda_2+\lambda_3)} > 0,$$
$$\lambda_4 - \frac{1}{4}|\lambda_5| + \sqrt{2\lambda_1(2\lambda_2+\lambda_3)} > 0.$$

Perturbative unitarity

$$|\lambda_4 - \lambda_5| < 2\pi, \qquad |2\lambda_3 + \lambda_2| < \pi,$$
$$|6\lambda_1 + 7\lambda_3 + 11\lambda_2| + \sqrt{(6\lambda_1 - 7\lambda_3 - 11\lambda_2)^2 + 36\lambda_4^2} < 4\pi,$$
$$|2\lambda_1 - \lambda_3 + 2\lambda_2| + \sqrt{(2\lambda_1 + \lambda_3 - 2\lambda_2)^2 + \lambda_5^2} < 4\pi.$$

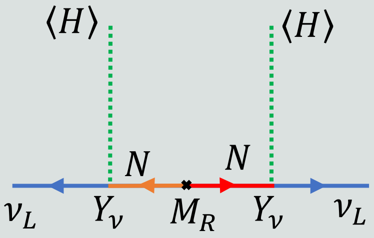
Nucl.Phys.B 262 (1985) 463-477， *JHEP* 01 (2013) 026， *JHEP* 01 (2016) 120

3、W-Boson Mass and CEPC constraints on the the GM Model

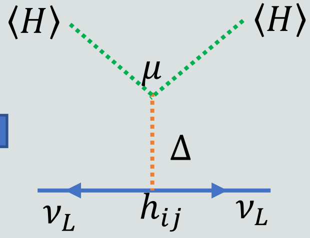
① $\Delta v = v_\chi - v_\xi > 0$ ⟶ $\cancel{SU(2)_c}$ ⟵ h_{ij} ↑ ⟵ Type I + Type II ②

Δm_W ↑

1. hypercharge gauge boson loops as a consequence of $SU(2)_L \times SU(2)_R$ breaking effects in the kinetic term.
2. Loop contributions contain ultra-violet (UV) divergences which cannot be cancelled by counterterms associated with the Vcust part alone.
3. …



$$M_\nu = -\langle H\rangle^2 Y_\nu M_R^{-1} Y_\nu^T$$



$$M_\nu = \langle H\rangle^2 h_{ij}\mu / M_\Delta^2$$

$$-\mathcal{L}_\nu \supset y_{ij}^N \bar{L}_{L,i}\phi N_{R,j} + \frac{1}{2}(M_R)_{ij} N_{R.i}^T C N_{R,j} + h_{ij}\overline{L_L^{ic}} i\tau_2 \chi L_L^j + h.c.$$

$$M_\nu = \begin{pmatrix} h_{ij}v_\Delta & \left(y_{ij}^N\right)^T v_\phi \\ y_{ij}^N v_\phi & (M_R)_{ij} \end{pmatrix} \quad M_R \gg v_\phi \gg v_\Delta$$

Phys.Rev.D 98 (2018) 1, 013008 , Phys.Lett.B 774 (2017) 119-122

3、W-Boson Mass and CEPC constraints on the the GM Model

2

$$\text{Type-I + Type-II} \longrightarrow h_{ij}\uparrow \longrightarrow \cancel{SU(2)_c} \longrightarrow \Delta m_W\uparrow$$

$$-\mathcal{L}_\nu \supset y^N_{ij}\overline{L}_{L,i}\phi N_{R,j} + \frac{1}{2}(M_R)_{ij}N^T_{R.i}CN_{R,j} + h_{ij}\overline{L^{ic}_L}i\tau_2\chi L^j_L + h.c.$$

$$m_\nu \approx h_{ij}v_\Delta - v_\phi^2\left(y^N_{ij}\right)^T M^{-1}_{R,j}\left(y^N_{ij}\right), \qquad h_{ij}v_\Delta \approx \left(y^N v_\phi\right)^2/M^{-1}_{R,j}$$

$$h_{ij} = 2\sqrt{2}\left(V^T_{PMNS}\right)^{-1}\left(\frac{v(1-s_H^2)}{s_H M_{R,i}}\right)\delta_{ij}(V_{PMNS})^{-1}, \qquad y^N_{ij} = (V_{PMNS})^{-1}$$

$BR(\mu \to e\gamma) < 4.2\times10^{-13}$,
$BR(\mu \to 3e) < 10^{-12}$

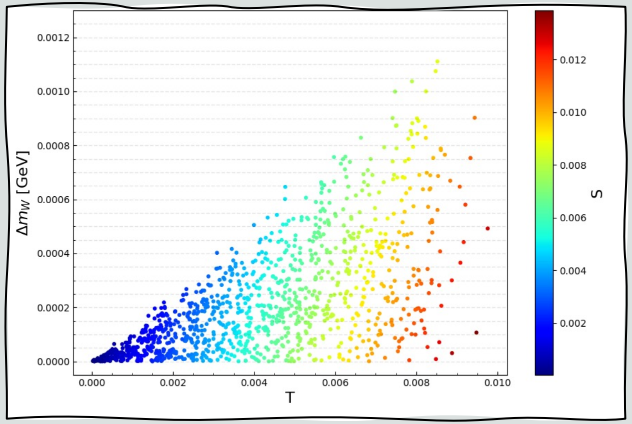
……

$$BR(\mu \to e\gamma) \sim \frac{\alpha_{EM}}{192\pi}\left|h_{ij}\right|^4\left(\frac{m_W}{M_{H^{++}}}\right)^4$$

$$h_{ij} < 10^{-2}, \qquad M_R > 50\text{TeV}$$

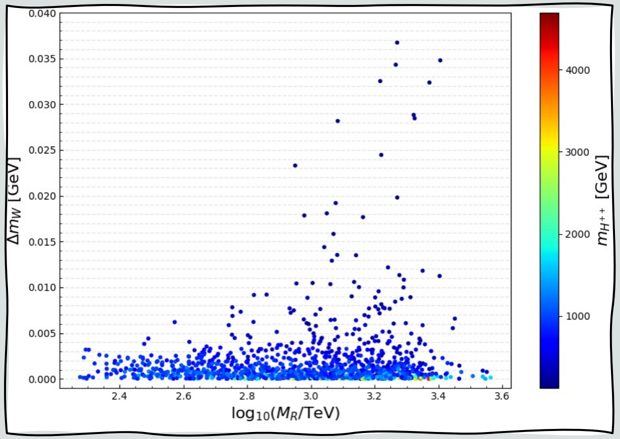
3、W-Boson Mass and CEPC constraints on the the GM Model

original GM Model



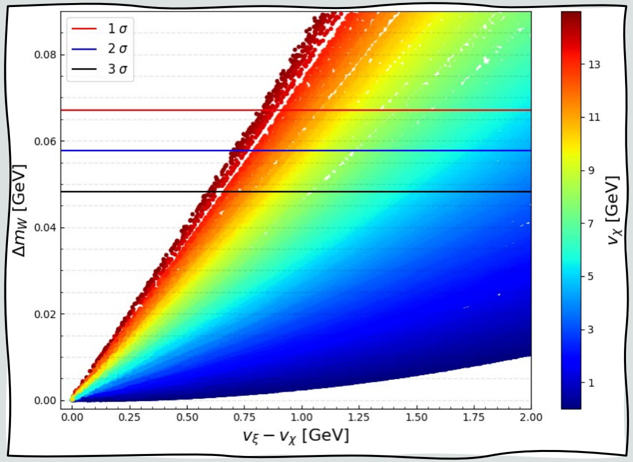
2

Type-I
+
Type-II

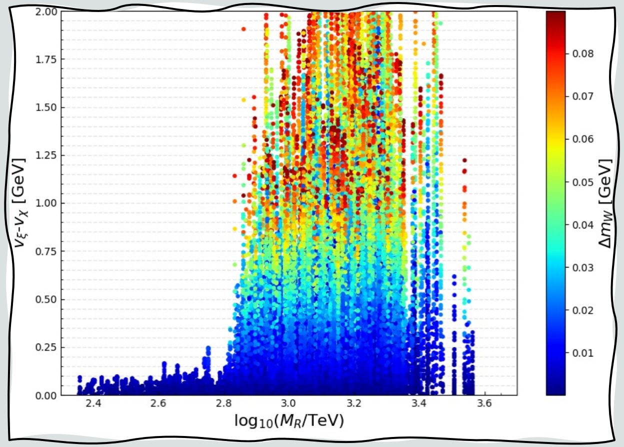


1

$v_\chi \neq v_\xi$

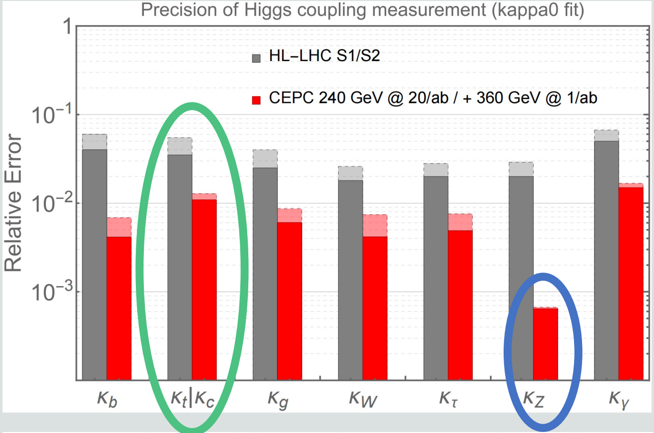


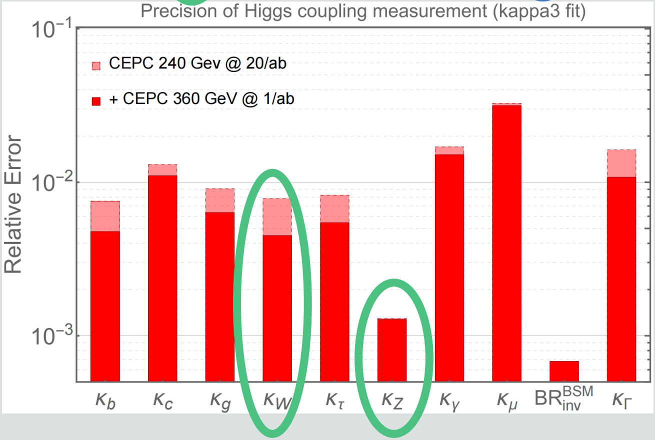
1
+
2



3、W-Boson Mass and CEPC constraints on the the GM Model

Precision of Higgs coupling measurement At CEPC

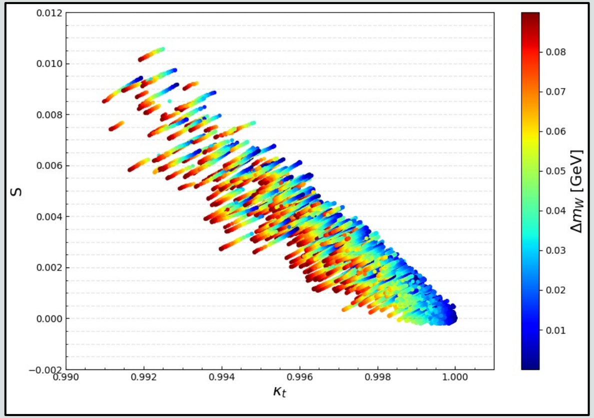




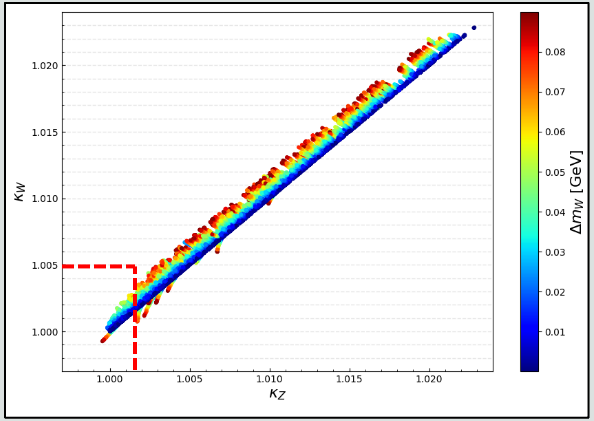
CEPC Snowmass report
arXiv:2205.08553

2

Type-I
+
Type-II



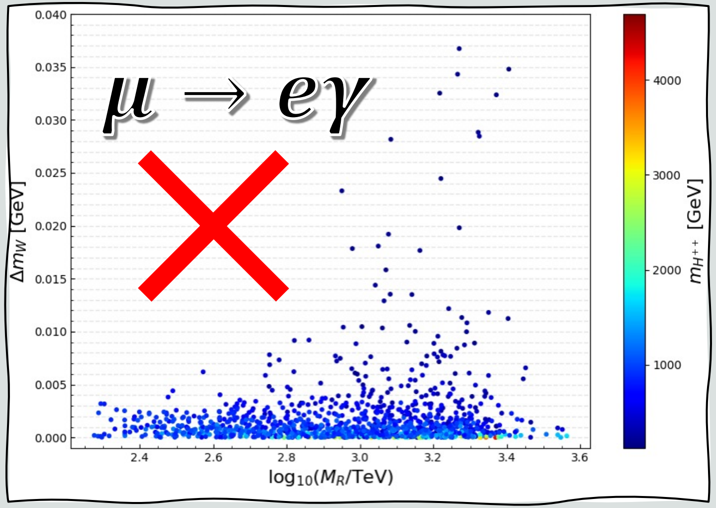
1
+
2

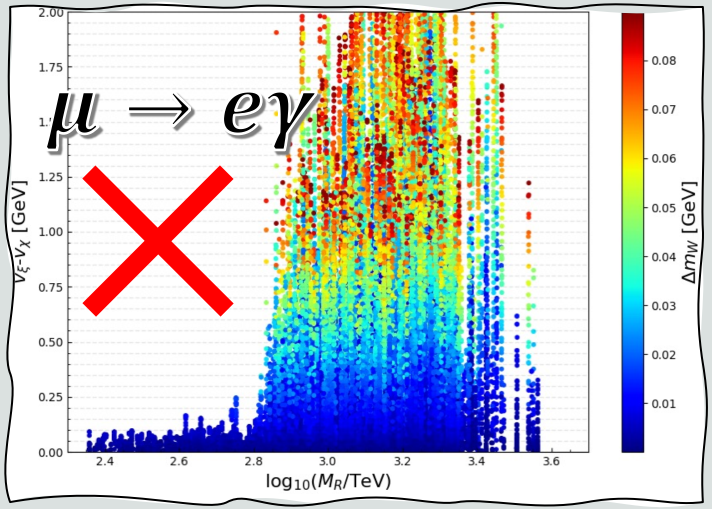


3、W-Boson Mass and CEPC constraints on the the GM Model

2 Type-I + Type-II

1 + 2





$Br(\mu \to e\gamma) < 4.2\times10^{-13}$ MEG(2016)

$< 6\times10^{-14}$ MEG II

$Br(\tau \to e\mu\mu) < 2.7\times10^{-8}$ Bell(2010)

$< \sim10^{-10}$ FCC/CEPC

CONTENTS

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Introduction to the Georgi-Machacek Model

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W-Boson Mass and CEPC constraints on the the GM Model

04

Summary and Q&A

4、Summary and Q&A

1. Improved the Vacuum Stability Constraint on the GM model ;

2. Taken a general discussion about the contribution to W boson mass in the original GM Model; Explaining CDF-II results in the GM Extension Models;

3. Discussed the CEPC constraints on the GM model, especially the lepton flavor violation constraints.

4、Summary and Q&A

THANKS

Q&A