An $SU(5)$ Unification Model*

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*I.D. and Shaikh Saad, Phys.Rev.D 101 (2020) 1, 015009, arXiv:1910.09008.
I.D., Emina Džaferović-Mašić, and Shaikh Saad, Phys.Rev.D 104 (2021) 1, 015023, arXiv:2105.01678.

OUTLINE

- **NOVEL *SU*(5) MODEL PROPOSAL**
- **PARAMETER SPACE ANALYSIS**
- **CONCLUSIONS**

GEORGI-GLASHOW MODEL*

$SU(5)$	$SU(3)\times SU(2)\times U(1)$	$SU(5)$	$SU(3)\times SU(2)\times U(1)$
$5_H \equiv \Lambda$	$\Lambda_1\,(1,2,\frac{1}{2})$ $\Lambda_3\,(3,1,-\frac{1}{3})$	$\overline{5}_{F\,i} \equiv F_i$	$L_i\,(1,2,-\frac{1}{2})$ $d_i^c\,(\overline{3},1,\frac{1}{3})$
$24_H \equiv \phi$	$\phi_0\,(1,1,0)$ $\phi_1\,(1,3,0)$ $\phi_3\,(3,2,-\frac{5}{6})$ $\phi_{\overline{3}}\,(\overline{3},2,\frac{5}{6})$ $\phi_8\,(8,1,0)$	$10_{F\,i} \equiv T_i$	$Q_i\,(3,2,\frac{1}{6})$ $u_i^c\,(\overline{3},1,-\frac{2}{3})$ $e_i^c\,(1,1,1)$

*H. Georgi and S.L. Glashow, Phys. Rev. Lett. 32 (1974) 438–441.

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- NEUTRINOS ARE MASSLESS
- GAUGE COUPLING UNIFICATION DOES NOT TAKE PLACE
- $m_e=m_d$, $m_\mu=m_s$, $m_\tau=m_b$

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A NOVEL *SU*(5) MODEL PROPOSAL*

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		$15_F \equiv \Sigma$	$\Sigma_1(1,3,1)$ $\Sigma_3\,(3,2,\frac{1}{6})$ $\Sigma_6\,(6,1,-\frac{2}{3})$
$35_H \equiv \Phi$	$\Phi_1\,(1,4,-\frac{3}{2})$ $\Phi_3\,(\overline{3},3,-\frac{2}{3})$ $\Phi_6\,(\overline{6},2,\frac{1}{6})$ $\Phi_{10}\,(\overline{10},1,1)$	$\overline{15}_F \equiv \overline{\Sigma}$	$\overline{\Sigma}_1\,(1,3,-1)$ $\overline{\Sigma}_3\,(\overline{3},2,-\frac{1}{6})$ $\overline{\Sigma}_6\,(\overline{6},1,\frac{2}{3})$

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$\langle\Lambda_1\rangle \equiv v_5$ - electroweak VEV $\quad \langle\phi_0\rangle \equiv v_{24}$ - $SU(5)$ breaking VEV

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*N. Oshimo,, Phys.Rev.D 80 (2009) 075011, arXiv:0907.3400.

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A NOVEL *SU*(5) MODEL PROPOSAL

$$\mathcal{L} \supset \Big\{ +Y^u_{ij}\, T^{\alpha\beta}_i T^{\gamma\delta}_j \Lambda^\rho \epsilon_{\alpha\beta\gamma\delta\rho} + Y^d_{ij}\, T^{\alpha\beta}_i F_{\alpha j} \Lambda^*_\beta + Y^a_i\, \Sigma^{\alpha\beta} F_{\alpha i} \Lambda^*_\beta + Y^b_i\, \overline{\Sigma}_{\beta\gamma} F_{\alpha i} \Phi^{*\alpha\beta\gamma}$$

$$+Y^c_i\, T^{\alpha\beta}_i \overline{\Sigma}_{\beta\gamma} \phi^\gamma_\alpha + \text{h.c.} \Big\} + M_\Sigma \overline{\Sigma}_{\alpha\beta} \Sigma^{\alpha\beta} + y\, \overline{\Sigma}_{\alpha\beta} \Sigma^{\beta\gamma} \phi^\alpha_\gamma$$

$$- \mu^2_\Lambda\, \left(\Lambda^*_\alpha \Lambda^\alpha\right) + \lambda^\Lambda_0\, \left(\Lambda^*_\alpha \Lambda^\alpha\right)^2 + \mu_1\, \Lambda^*_\alpha \Lambda^\beta \phi^\alpha_\beta + \lambda^\Lambda_1\, \left(\Lambda^*_\alpha \Lambda^\alpha\right) \left(\phi^\beta_\gamma \phi^\gamma_\beta\right) + \lambda^\Lambda_2\, \Lambda^*_\alpha \Lambda^\beta \phi^\gamma_\beta \phi^\alpha_\gamma$$

$$- \mu^2_\phi\, \left(\phi^\beta_\gamma \phi^\gamma_\beta\right) + \mu_2\, \phi^\alpha_\beta \phi^\beta_\gamma \phi^\gamma_\alpha + \lambda^\phi_0\, \left(\phi^\beta_\gamma \phi^\gamma_\beta\right)^2 + \lambda^\phi_1\, \phi^\alpha_\beta \phi^\beta_\gamma \phi^\gamma_\delta \phi^\delta_\alpha + \mu^2_\Phi\, \left(\Phi^{*\alpha\beta\gamma} \Phi_{\alpha\beta\gamma}\right)$$

$$+ \lambda^\Phi_0\, \left(\Phi^{*\alpha\beta\gamma} \Phi_{\alpha\beta\gamma}\right)^2 + \lambda^\Phi_1\, \Phi^{*\alpha\beta\gamma} \Phi_{\alpha\beta\delta} \Phi^{*\delta\rho\sigma} \Phi_{\rho\sigma\gamma} + \lambda_0\, \left(\Phi^{*\alpha\beta\gamma} \Phi_{\alpha\beta\gamma}\right) \left(\phi^\delta_\rho \phi^\rho_\delta\right)$$

$$+ \lambda'_0\, \left(\Phi^{*\alpha\beta\gamma} \Phi_{\alpha\beta\gamma}\right) \left(\Lambda^*_\rho \Lambda^\rho\right) + \lambda''_0\, \Phi^{*\alpha\beta\gamma} \Phi_{\beta\gamma\delta} \Lambda^\delta \Lambda^*_\alpha + \mu_3\, \Phi^{*\alpha\beta\gamma} \Phi_{\beta\gamma\delta} \phi^\delta_\alpha$$

$$+ \lambda_1\, \Phi^{*\alpha\beta\gamma} \Phi_{\alpha\delta\rho} \phi^\delta_\beta \phi^\rho_\gamma + \lambda_2\, \Phi^{*\alpha\beta\rho} \Phi_{\alpha\beta\delta} \phi^\gamma_\rho \phi^\delta_\gamma\, + \left\{ \lambda'\, \Lambda^\alpha \Lambda^\beta \Lambda^\gamma \Phi_{\alpha\beta\gamma} + \text{h.c.} \right\}$$

A NOVEL *SU*(5) MODEL PROPOSAL

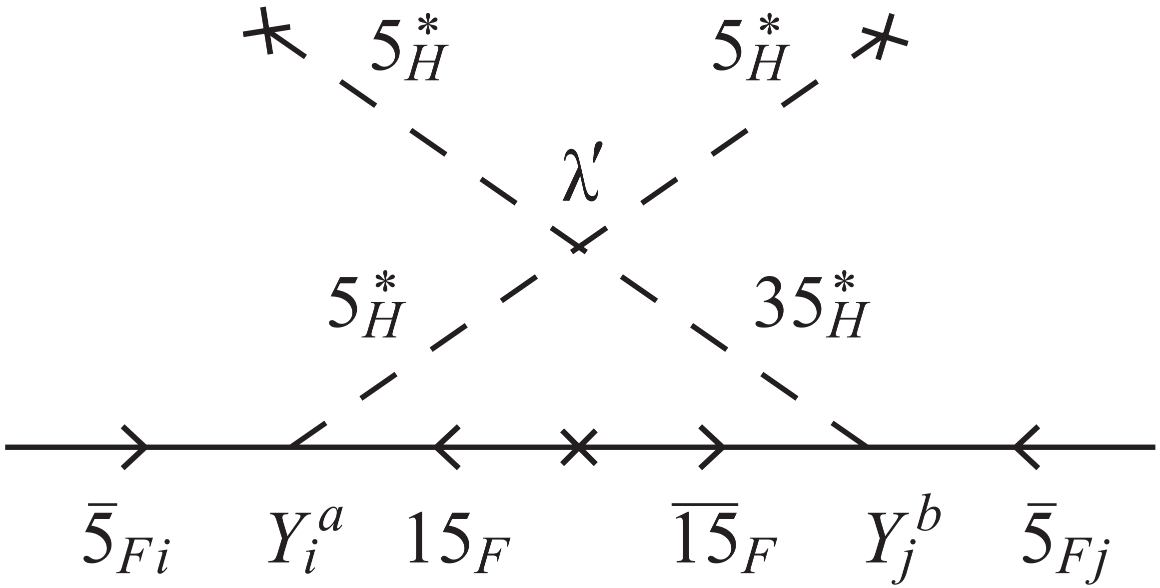
PARTICLE CONTENT:

$$5_H\,,\ 24_H\,,\ 35_H\,,\ \overline{5}_{F\,i},\ 10_{F\,i},\ 15_F,\ \overline{15}_F \qquad i=1,2,3$$

YUKAWA COUPLINGS:

$$Y_i^a,\ Y_i^b,\ Y_i^c,\ Y_{ij}^u,\ Y_{ij}^d,\ y \qquad i,j=1,2,3$$

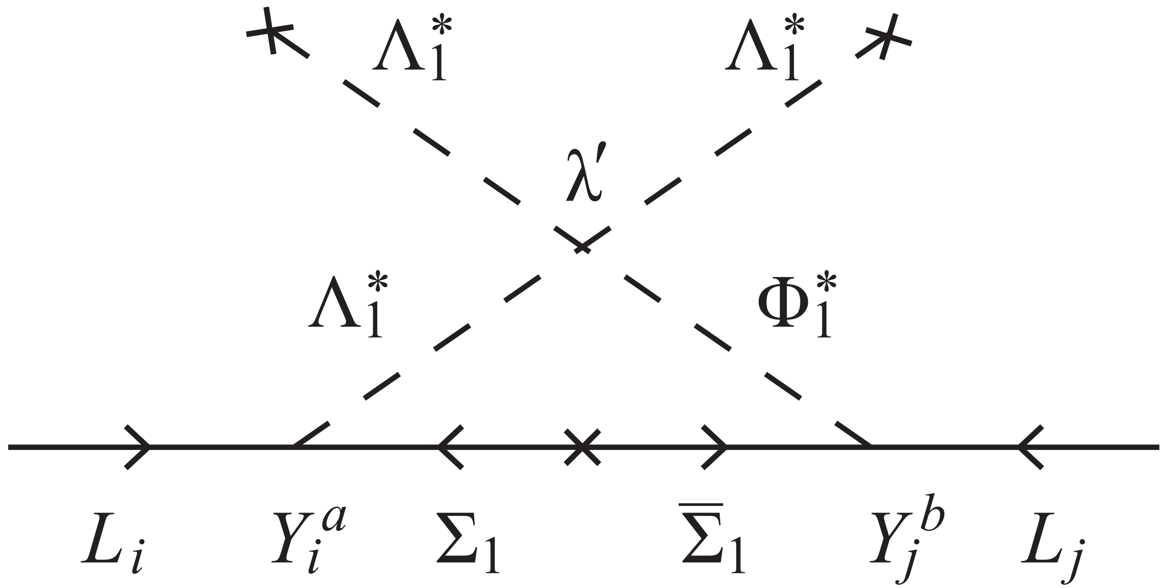
NEUTRINO MASSES *



$$\mathcal{L} \supset \lambda' \, 5_H 5_H 5_H 35_H + Y_i^a \, 15_F \bar{5}_{Fi} 5_H^* + Y_i^b \, \overline{15}_F \bar{5}_{Fi} 35_H^*$$

*I.D. and Shaikh Saad, Phys.Rev.D 101 (2020) 1, 015009, arXiv:1910.09008.

NEUTRINO MASSES *



$$(M_N)_{ij} = m_0 \left(Y_i^a Y_j^b + Y_i^b Y_j^a\right) \qquad m_0 = \frac{\lambda' v_5^2}{16\pi^2} \frac{M_{\Sigma_1}}{M_{\Sigma_1}^2 - M_{\Phi_1}^2} \log\left(\frac{M_{\Sigma_1}^2}{M_{\Phi_1}^2}\right)$$

*K.S. Babu, S. Nandi, and Z. Tavartkiladze, Phys.Rev.D 80 (2009) 071702, arXiv:0905.2710.

CHARGED FERMION MASSES

GEORGI-GLASHOW MODEL:*

$$(M_U)_{ij} = 4v_5(Y^u_{ij} + Y^u_{ji})$$

$$(M_D)_{ij} = v_5 \;\; Y^d_{ij}$$

$$(M_E)_{ij} = v_5 Y^d_{ji}$$

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CHARGED FERMION MASSES

NOVEL PROPOSAL:*

$$(M_U)_{ij} = 4v_5(Y^u_{ij} + Y^u_{ji})$$

$$(M_D)_{ij} = v_5\left(Y^d_{ij} + \delta'\, Y^c_i Y^a_j\right)$$

$$(M_E)_{ij} = v_5 Y^d_{ji}$$

$$\delta' \equiv \sqrt{10/3}v_{24}/(4M_{\Sigma_3})$$

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FERMION MASSES *

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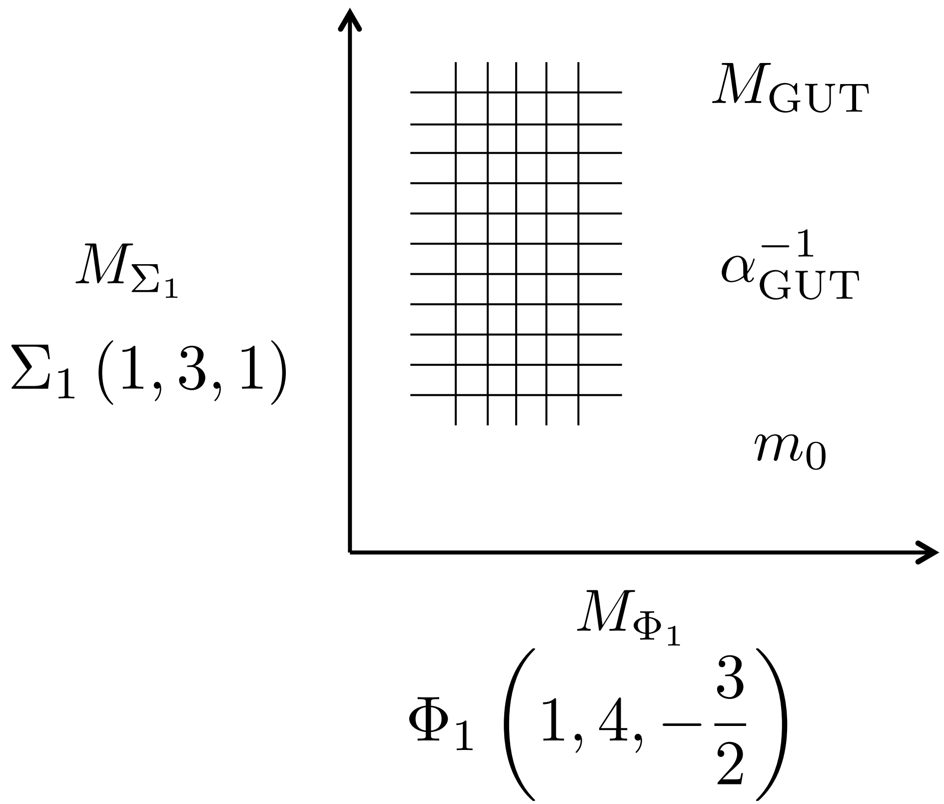
PARAMETER SPACE ANALYSIS *

- GAUGE COUPLING UNIFICATION ($\max(M_{\rm GUT})$)

$$M \equiv \min(M_J), \qquad J = \Phi_1, \Phi_3, \Phi_6, \Phi_{10}, \Sigma_1, \Sigma_3, \Sigma_6, \phi_1, \phi_8, \Lambda_3$$



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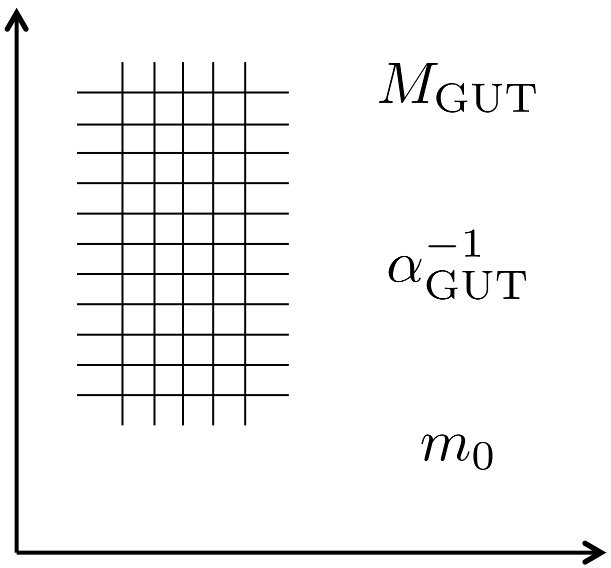
M_{Σ_1}

$\Sigma_1\,(1,3,1)$



$M_{\rm GUT}$

$\alpha^{-1}_{\rm GUT}$

m_0

M_{Φ_1}

$$\Phi_1\left(1, 4, -\frac{3}{2}\right)$$

- FERMION MASS FIT

$$(M_U)_{ij} = 4v_5(Y^u_{ij} + Y^u_{ji})$$

$$(M_D)_{ij} = v_5\left(Y^d_{ij} + \delta'\; Y^c_i Y^a_j\right)$$

$$(M_E)_{ij} = v_5 Y^d_{ji}$$

$$(M_N)_{ij} = m_0\left(Y^a_i Y^b_j + Y^b_i Y^a_j\right)^*$$

*I. Cordero-Carrión, M. Hirsch, and A. Vicente,, Phys.Rev.D 101 no. 7, (2020) 075032, arXiv:1912.08858.

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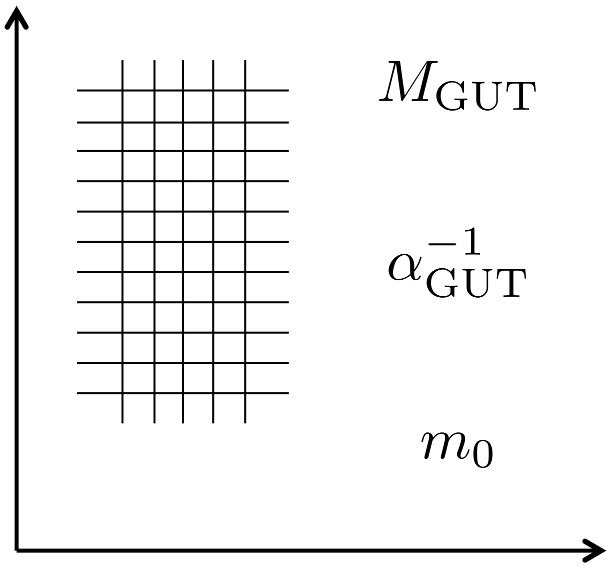

M_{Σ_1}

$\Sigma_1\,(1,3,1)$

M_{GUT}

$\alpha_{\mathrm{GUT}}^{-1}$

m_0

M_{Φ_1}

$\Phi_1\left(1,4,-\frac{3}{2}\right)$

- FERMION MASS FIT

- PROTON DECAY ANALYSIS

$$M_U = U_L M_U^{\mathrm{diag}} U_R^\dagger$$
$$M_D = D_L M_D^{\mathrm{diag}} D_R^\dagger$$
$$M_E \equiv E_L M_E^{\mathrm{diag}} E_R^\dagger$$
$$M_N = N M_N^{\mathrm{diag}} N^T$$

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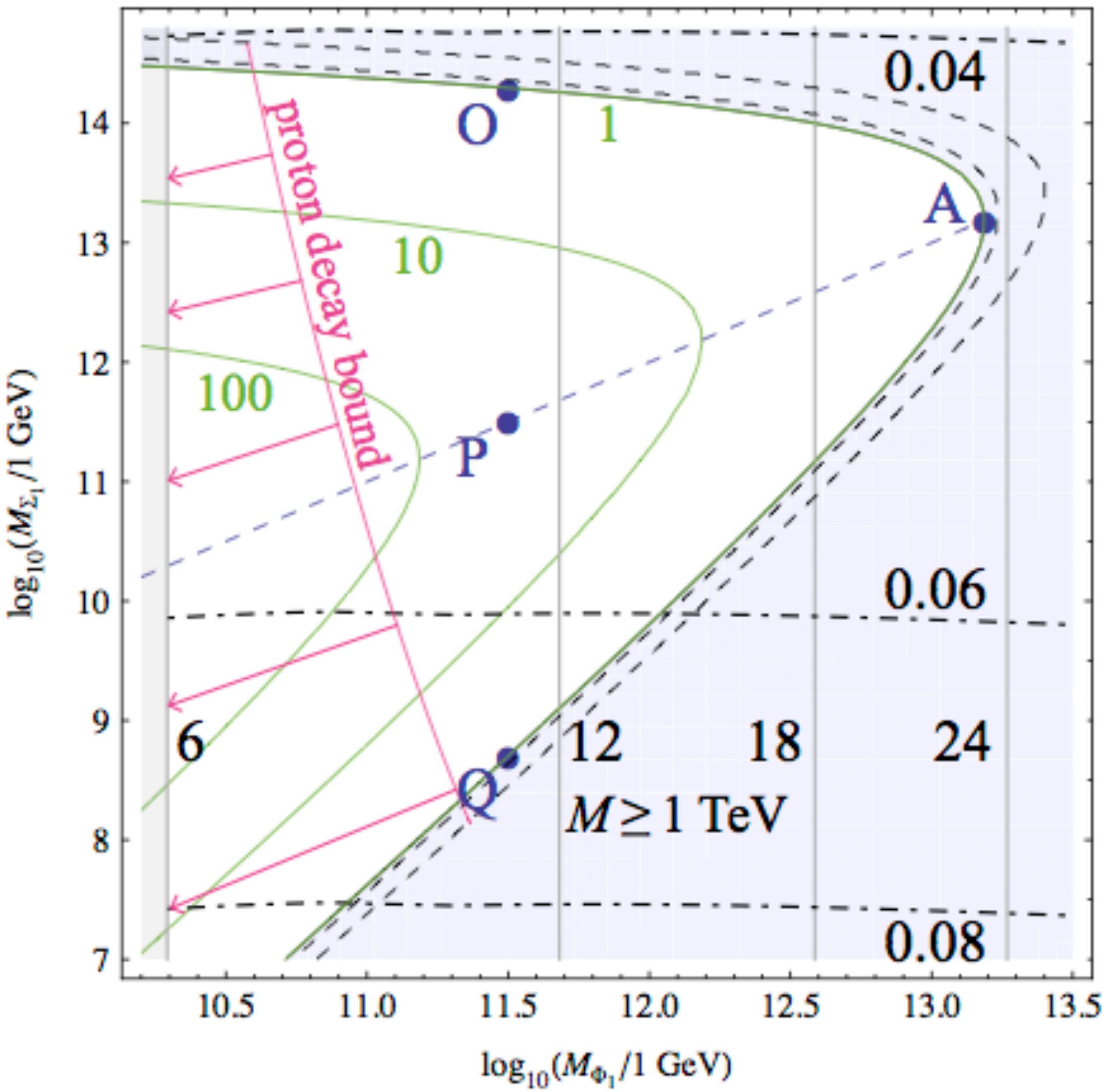
PARAMETER SPACE ANALYSIS *



*I.D., Emina Džaferović-Mašić, and Shaikh Saad, Phys.Rev.D 104 (2021) 1, 015023, arXiv:2105.01678.

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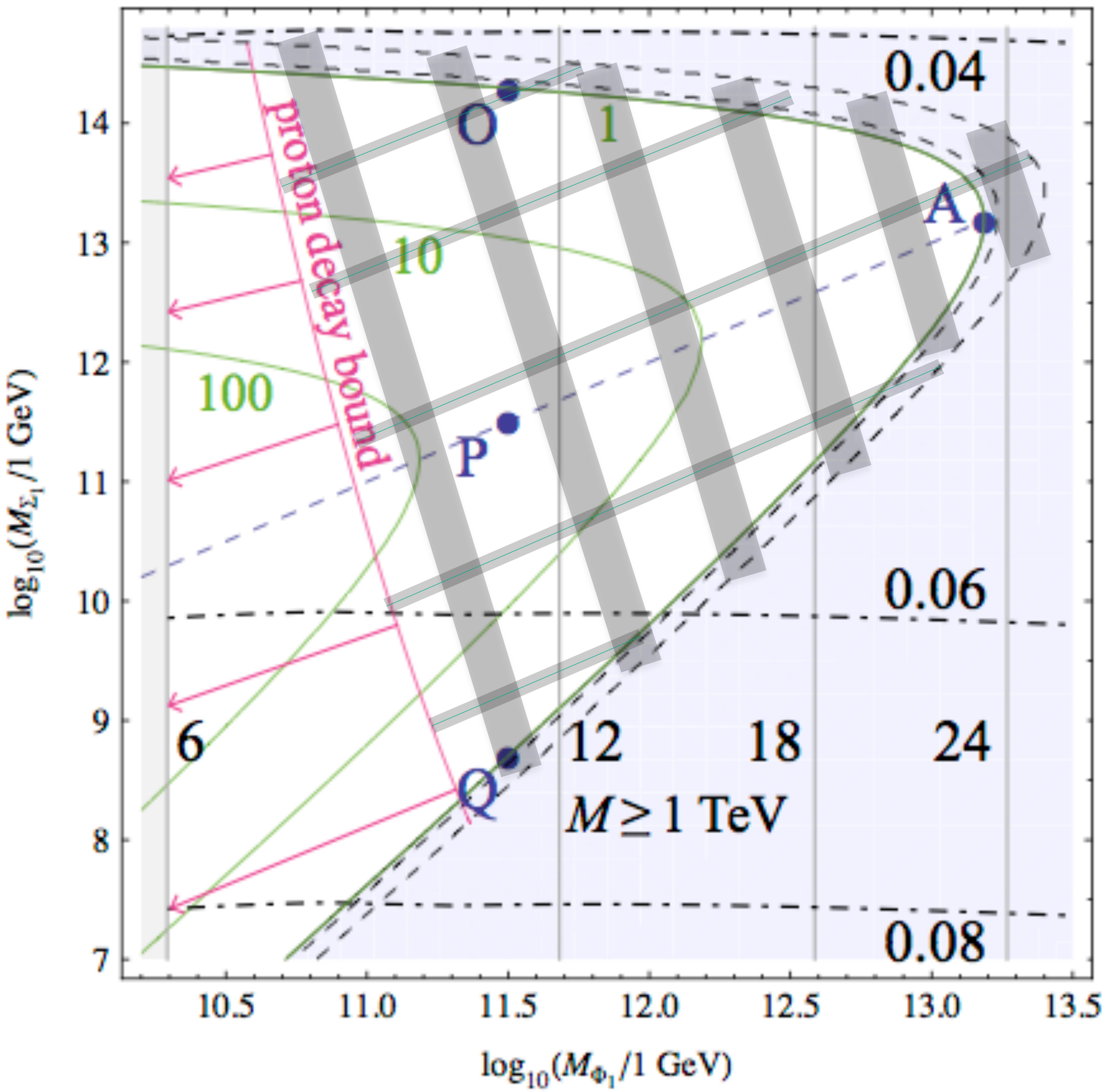

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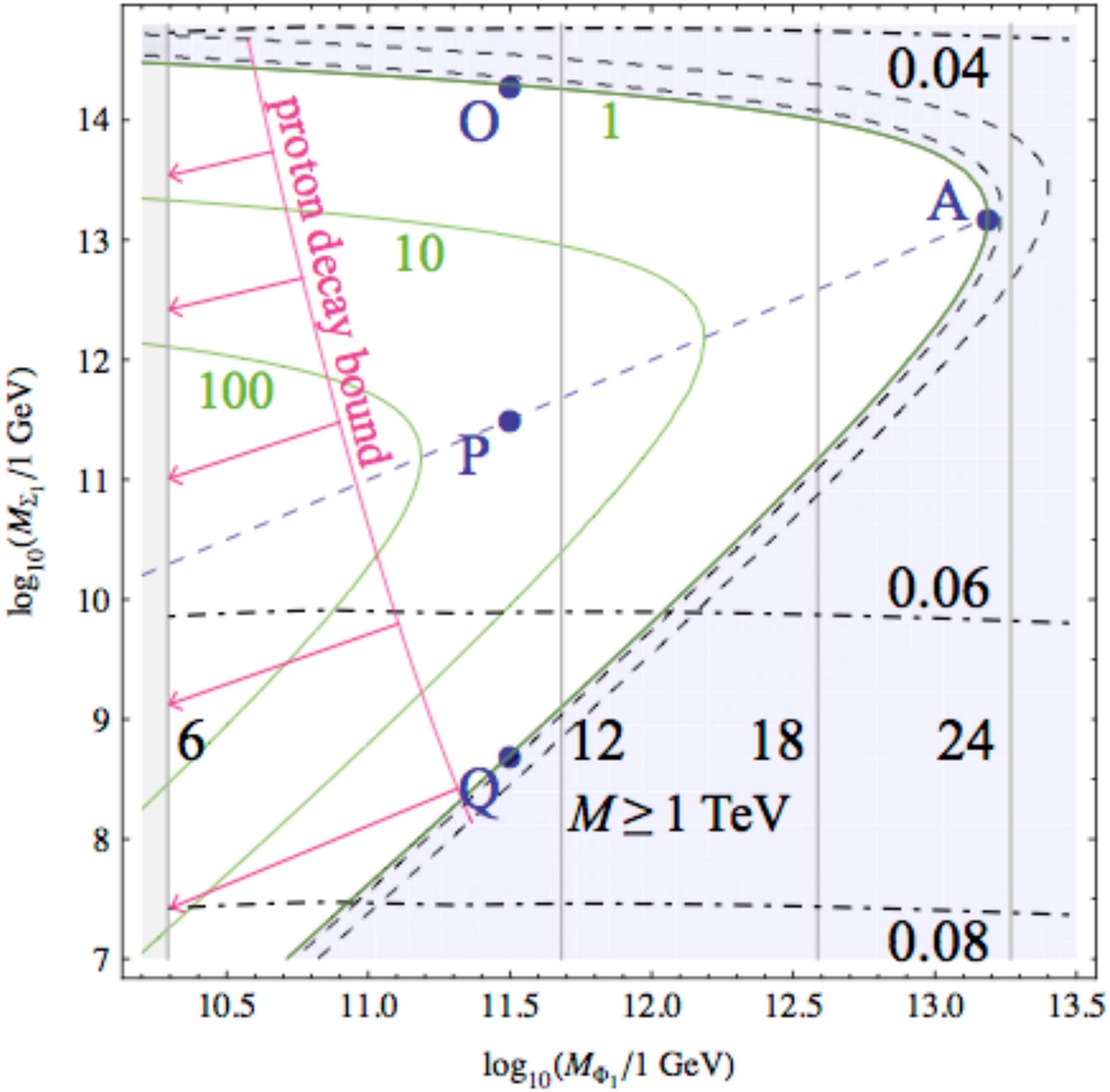

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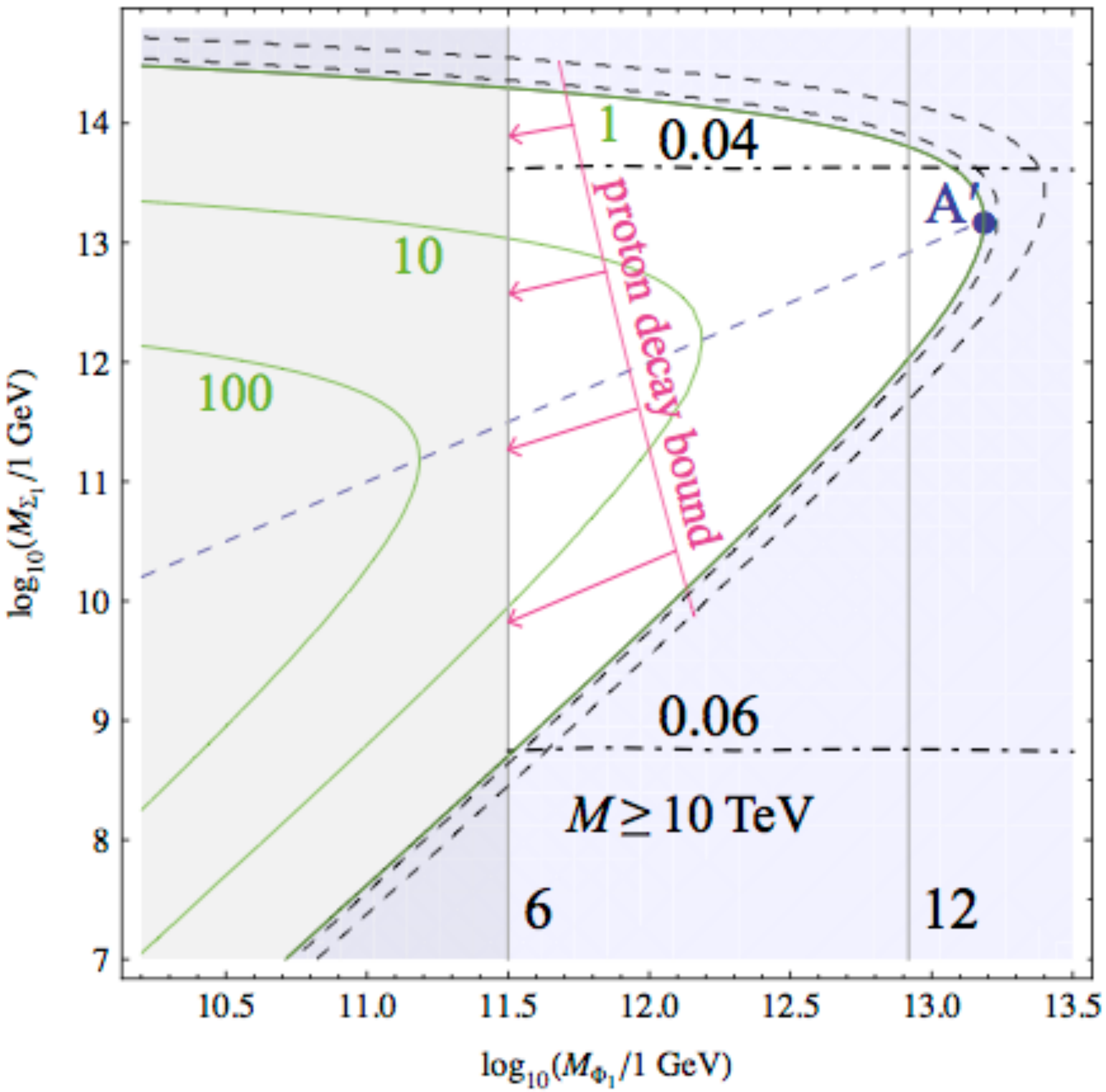

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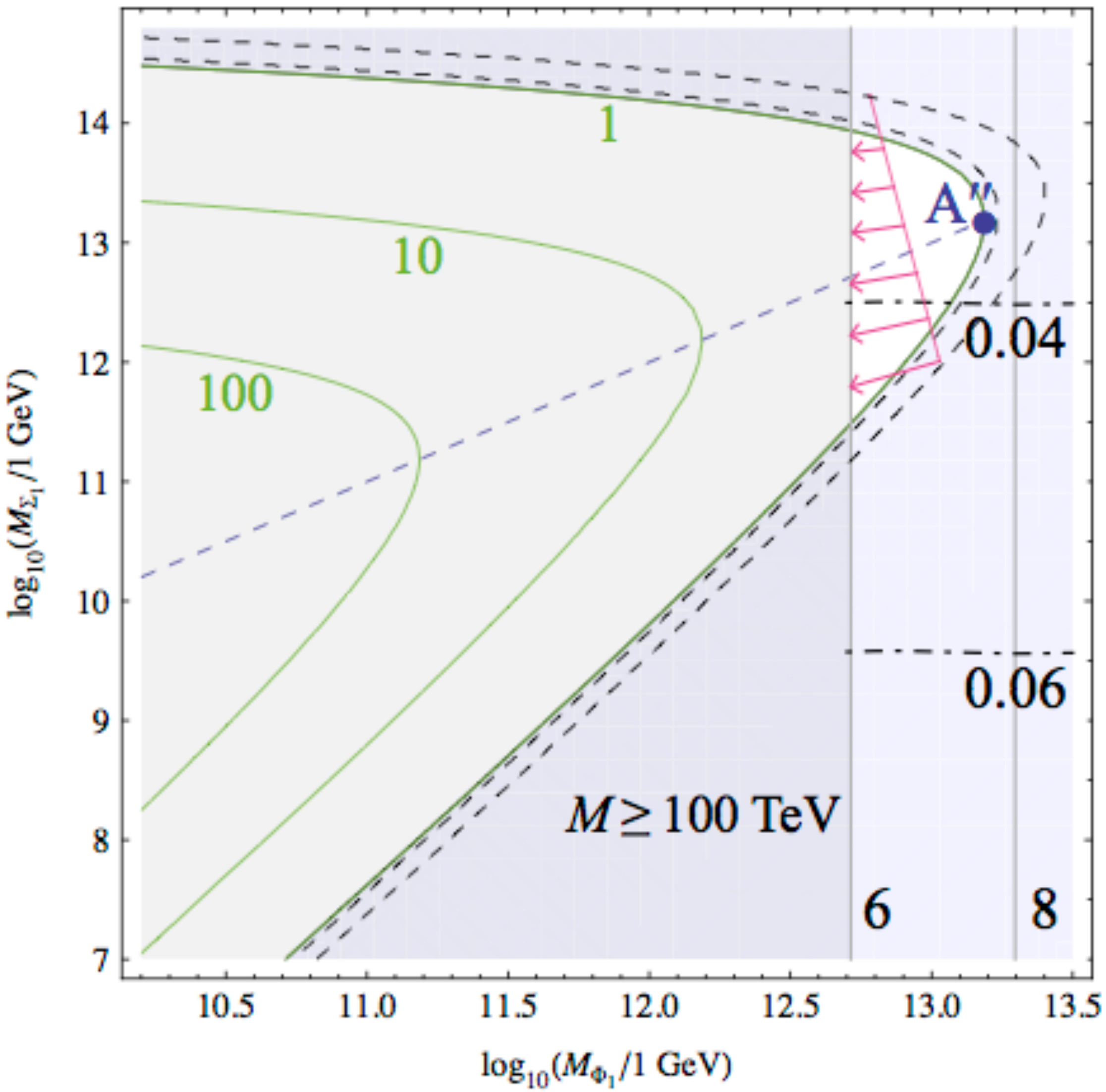

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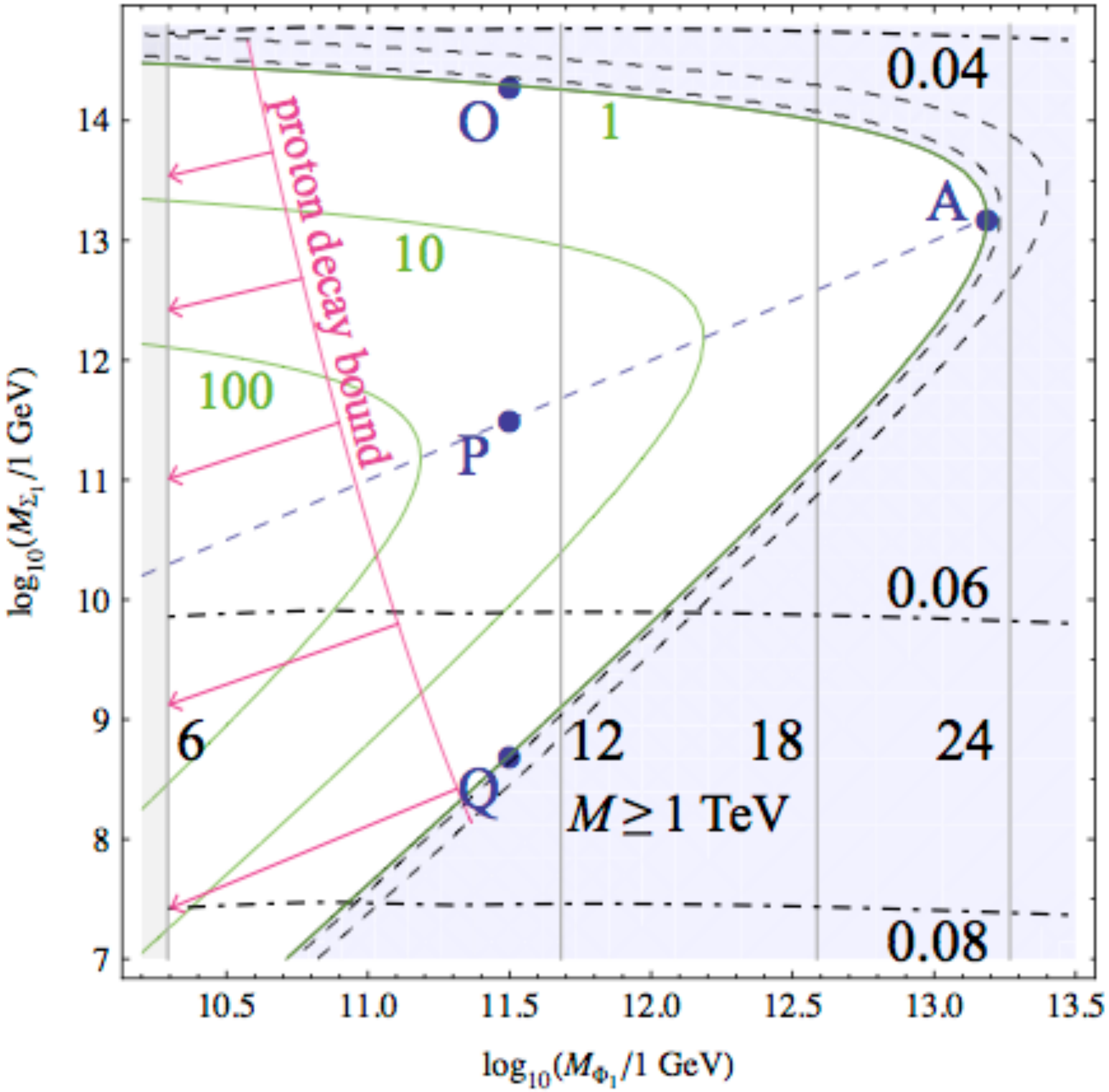

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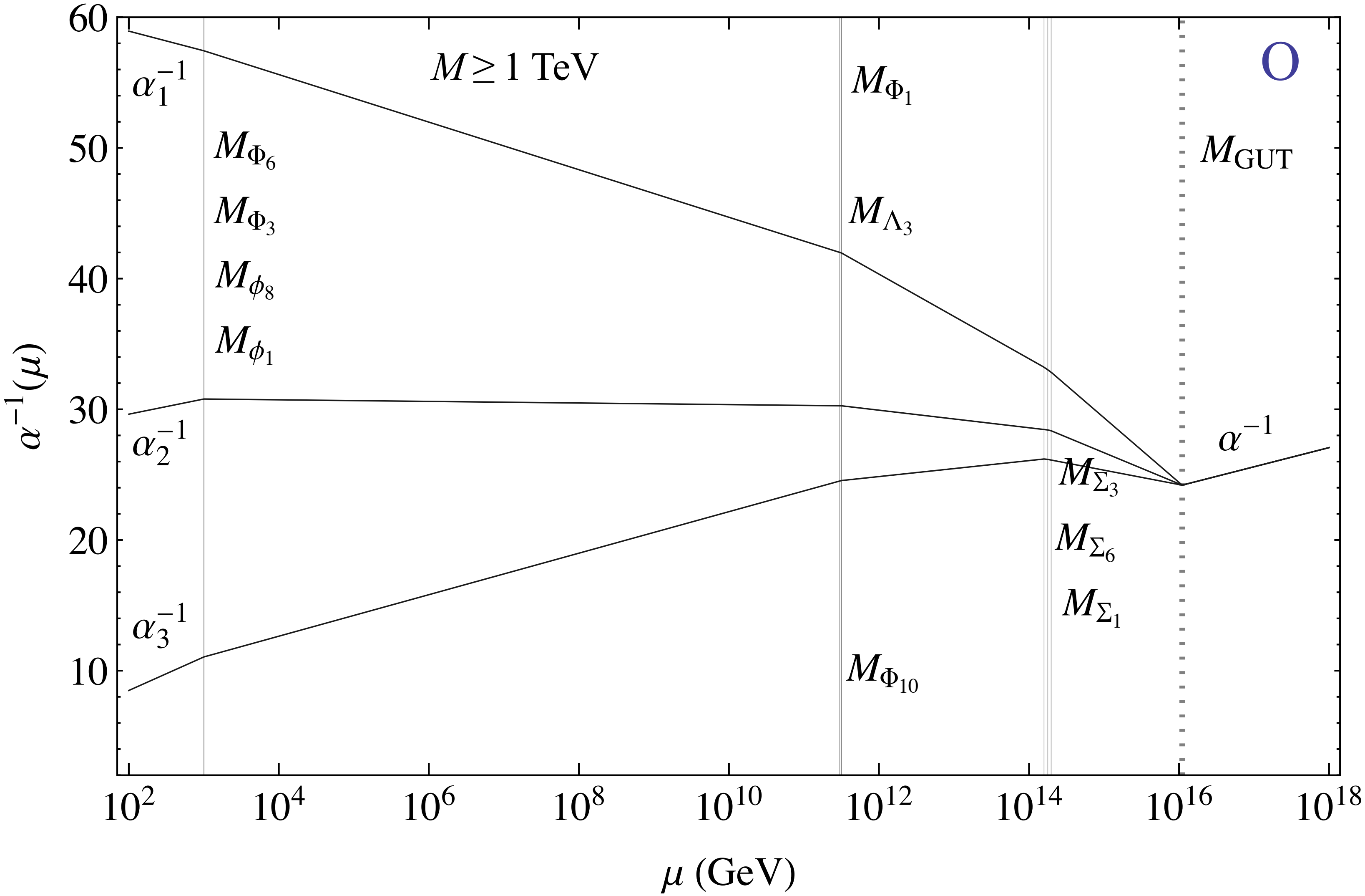

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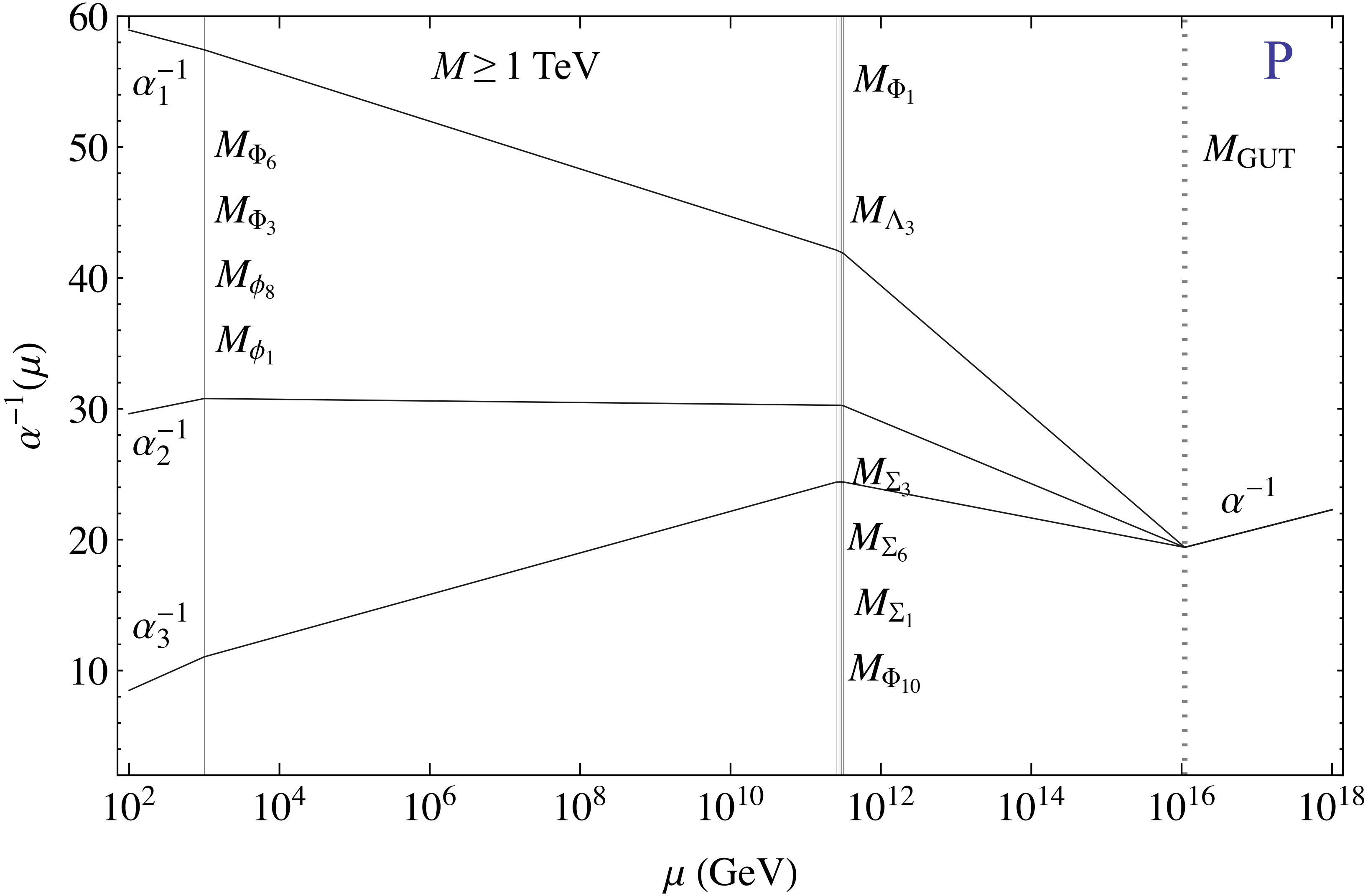

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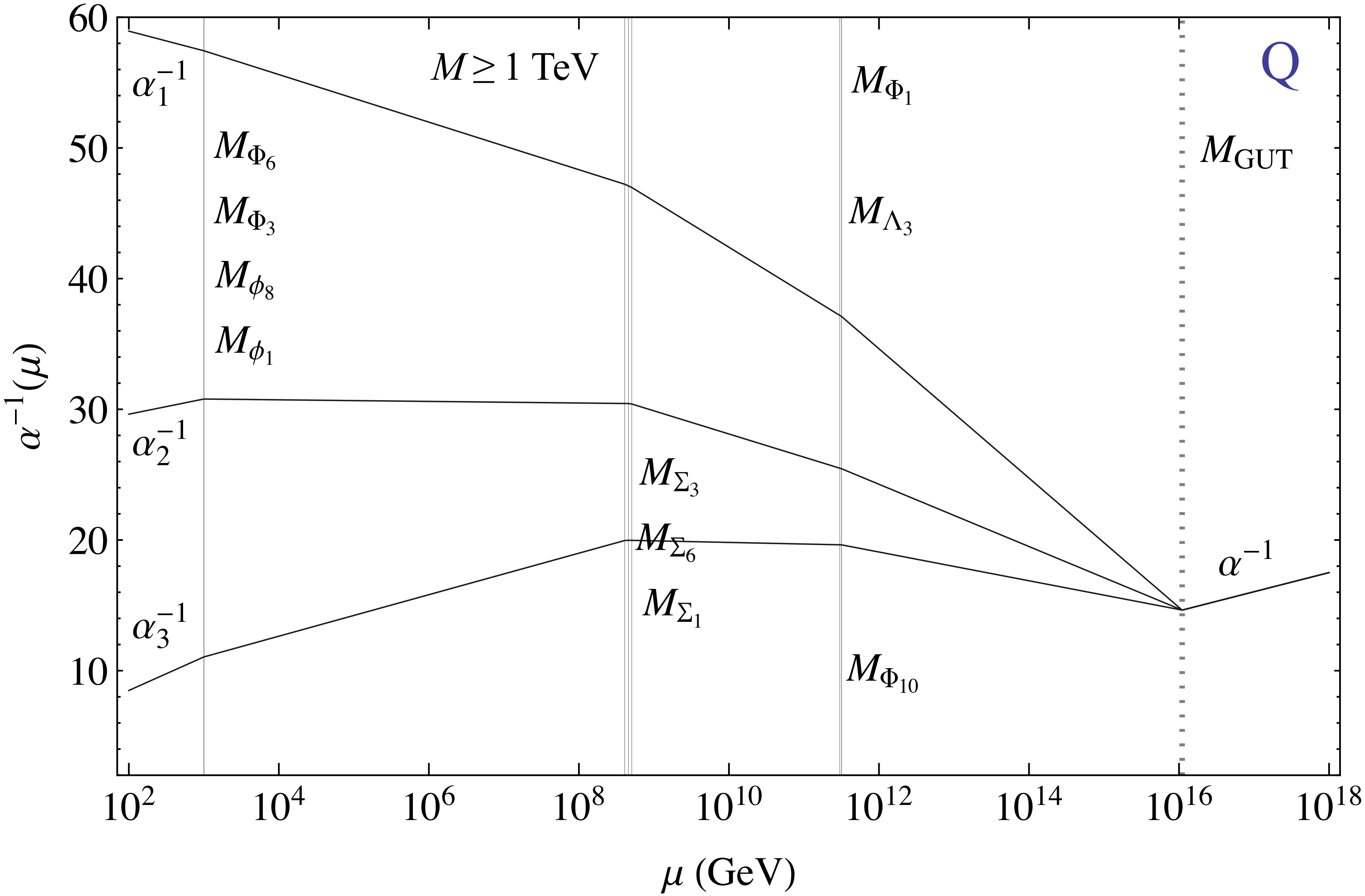

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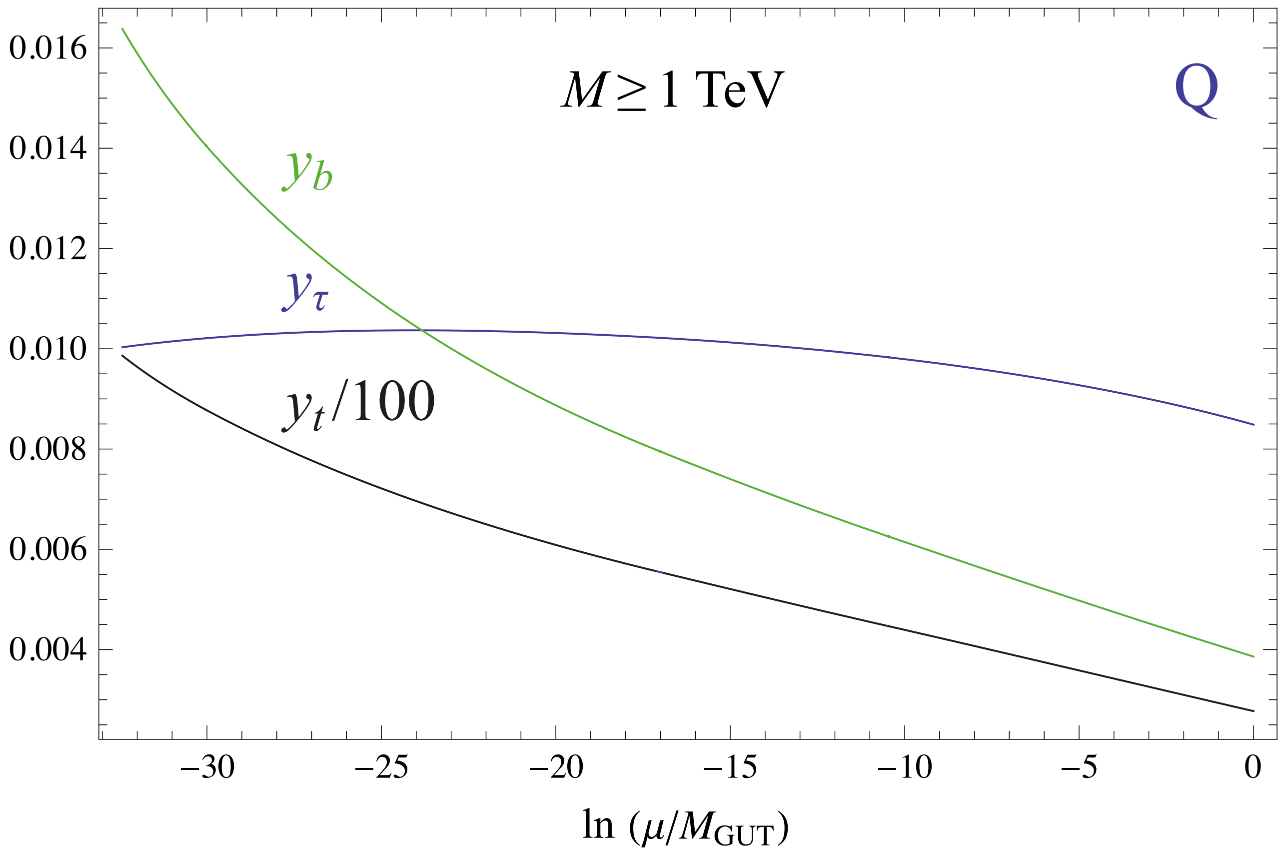

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CONCLUSIONS

PARTICLE CONTENT:

$$5_H,\ 24_H,\ 35_H,\ \overline{5}_{F\,i},\ 10_{F\,i},\ 15_F,\ \overline{15}_F \qquad i=1,2,3$$

YUKAWA COUPLINGS:

$$Y_i^a,\ Y_i^b,\ Y_i^c,\ Y_{ij}^u,\ Y_{ij}^d,\ y \qquad i,j=1,2,3$$

- NEUTRINOS ARE MAJORANA PARTICLES
- ONE NEUTRINO IS MASSLESS
- NEUTRINO MASSES HAVE NORMAL ORDERING

CONCLUSIONS

- CURRENT PROTON DECAY LIMITS REQUIRE THAT THERE ARE FOUR SCALAR MULTIPLETS AT 120 TeV IF THESE ARE TAKEN TO BE MASS DEGENERATE.
- THE MULTIPLETS IN QUESTION ARE: $\phi_1\,(1,3,0)$

$$\phi_8\,(8,1,0)$$

$$\Phi_3\left(\overline{3},3,-\frac{2}{3}\right)$$

$$\Phi_6\left(\overline{6},2,\frac{1}{6}\right)$$

CONCLUSIONS

- AN IMPROVEMENT OF THE CURRENT $p \to \pi^0 e^+$ LIFETIME LIMIT BY A FACTOR OF 2, 15, AND 96 WOULD REQUIRE THESE FOUR SCALAR MULTIPLETS TO RESIDE AT OR BELOW THE 100 TeV, 10 TeV, AND 1 TeV MASS SCALES, RESPECTIVELY.

$$
\begin{aligned}
\mathcal{L} \supset \Big\{ &+Y^u_{ij}\, T_i^{\alpha\beta} T_j^{\gamma\delta} \Lambda^\rho \epsilon_{\alpha\beta\gamma\delta\rho} + Y^d_{ij}\, T_i^{\alpha\beta} F_{\alpha j} \Lambda^*_\beta + Y^a_i\, \Sigma^{\alpha\beta} F_{\alpha i} \Lambda^*_\beta + Y^b_i\, \overline{\Sigma}_{\beta\gamma} F_{\alpha i} \Phi^{*\alpha\beta\gamma} \\
&+Y^c_i\, T_i^{\alpha\beta} \overline{\Sigma}_{\beta\gamma} \phi^\gamma_\alpha + \text{h.c.} \Big\} + M_\Sigma \overline{\Sigma}_{\alpha\beta} \Sigma^{\alpha\beta} + y\, \overline{\Sigma}_{\alpha\beta} \Sigma^{\beta\gamma} \phi^\alpha_\gamma \\
&- \mu^2_\Lambda\, \left(\Lambda^*_\alpha \Lambda^\alpha\right) + \lambda^\Lambda_0\, \left(\Lambda^*_\alpha \Lambda^\alpha\right)^2 + \mu_1\, \Lambda^*_\alpha \Lambda^\beta \phi^\alpha_\beta + \lambda^\Lambda_1\, \left(\Lambda^*_\alpha \Lambda^\alpha\right) \left(\phi^\beta_\gamma \phi^\gamma_\beta\right) + \lambda^\Lambda_2\, \Lambda^*_\alpha \Lambda^\beta \phi^\gamma_\beta \phi^\alpha_\gamma \\
&- \mu^2_\phi\, \left(\phi^\beta_\gamma \phi^\gamma_\beta\right) + \mu_2\, \phi^\alpha_\beta \phi^\beta_\gamma \phi^\gamma_\alpha + \lambda^\phi_0\, \left(\phi^\beta_\gamma \phi^\gamma_\beta\right)^2 + \lambda^\phi_1\, \phi^\alpha_\beta \phi^\beta_\gamma \phi^\gamma_\delta \phi^\delta_\alpha + \mu^2_\Phi\, \left(\Phi^{*\alpha\beta\gamma} \Phi_{\alpha\beta\gamma}\right) \\
&+ \lambda^\Phi_0\, \left(\Phi^{*\alpha\beta\gamma} \Phi_{\alpha\beta\gamma}\right)^2 + \lambda^\Phi_1\, \Phi^{*\alpha\beta\gamma} \Phi_{\alpha\beta\delta} \Phi^{*\delta\rho\sigma} \Phi_{\rho\sigma\gamma} + \lambda_0\, \left(\Phi^{*\alpha\beta\gamma} \Phi_{\alpha\beta\gamma}\right) \left(\phi^\delta_\rho \phi^\rho_\delta\right) \\
&+ \lambda'_0\, \left(\Phi^{*\alpha\beta\gamma} \Phi_{\alpha\beta\gamma}\right) \left(\Lambda^*_\rho \Lambda^\rho\right) + \lambda''_0\, \Phi^{*\alpha\beta\gamma} \Phi_{\beta\gamma\delta} \Lambda^\delta \Lambda^*_\alpha + \mu_3\, \Phi^{*\alpha\beta\gamma} \Phi_{\beta\gamma\delta} \phi^\delta_\alpha \\
&+ \lambda_1\, \Phi^{*\alpha\beta\gamma} \Phi_{\alpha\delta\rho} \phi^\delta_\beta \phi^\rho_\gamma + \lambda_2\, \Phi^{*\alpha\beta\rho} \Phi_{\alpha\beta\delta} \phi^\gamma_\rho \phi^\delta_\gamma\ + \left\{ \lambda'\, \Lambda^\alpha \Lambda^\beta \Lambda^\gamma \Phi_{\alpha\beta\gamma} + \text{h.c.} \right\}
\end{aligned}
$$

THANK YOU

dorsner@fesb.hr