The Minimal $SU(5)$ Unification Model*

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Corfu 2021 Summer Institute Workshop on Standard Model and Beyond
Corfu, Greece
September 5th, 2021

*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

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

GEORGI-GLASHOW MODEL*

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

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

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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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v_5 - electroweak VEV $\qquad$ v_{24} - SU(5) breaking VEV

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$$
\begin{aligned}
\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\} ,
\end{aligned}
$$

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\begin{aligned}
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& + 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\} ,
\end{aligned}
$$

A NOVEL *SU*(5) MODEL PROPOSAL

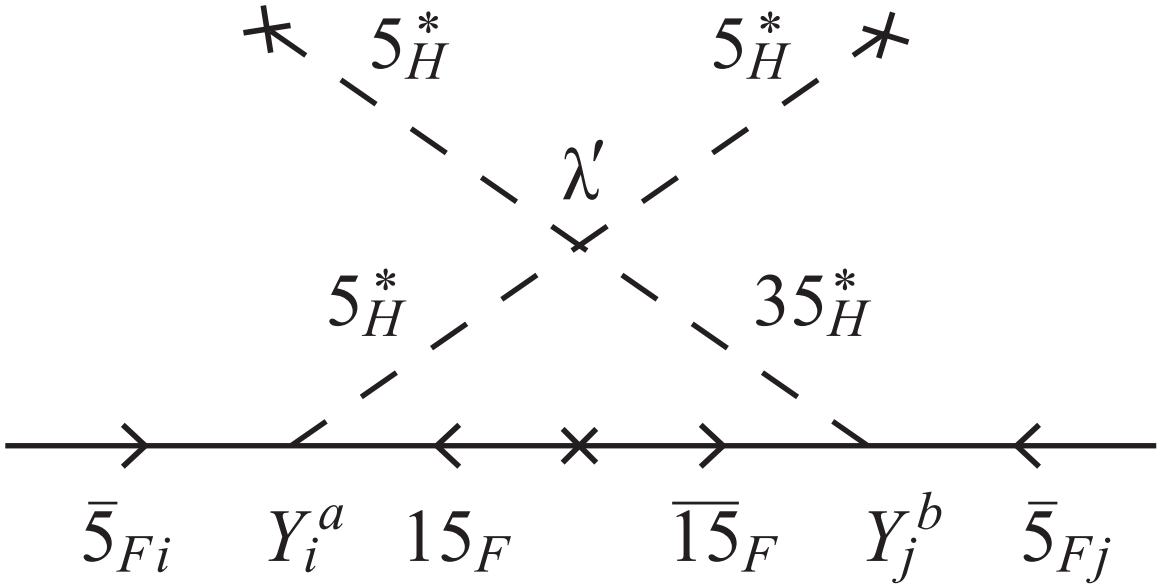
PARTICLE CONTENT:

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

YUKAWA COUPLINGS:

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

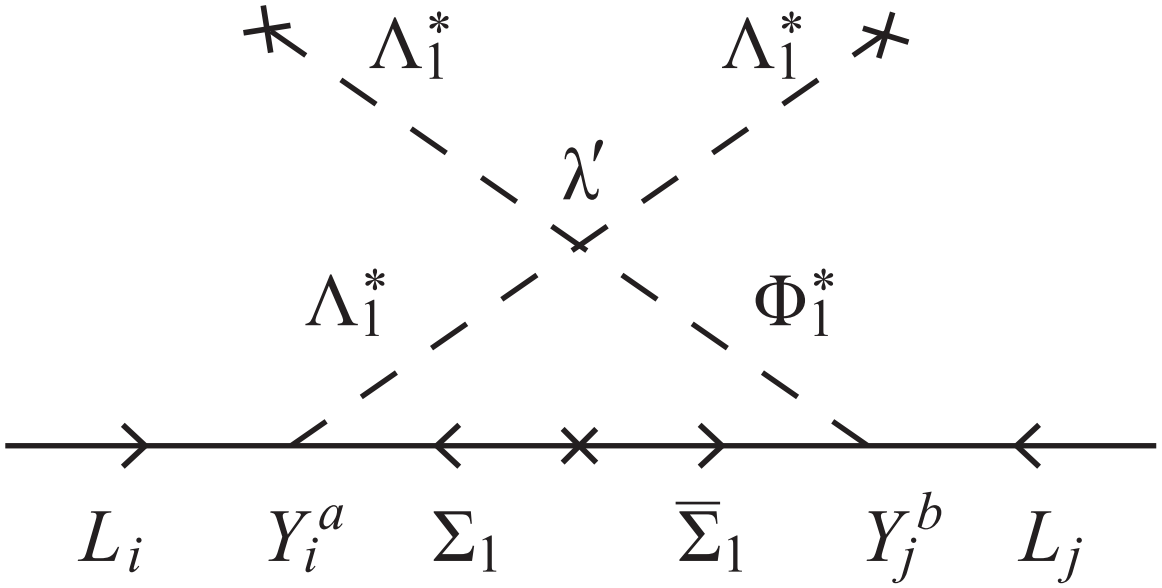
NEUTRINO MASSES *



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

*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:*

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

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

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

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

CHARGED FERMION MASSES *

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

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

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

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

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

FERMION MASSES *

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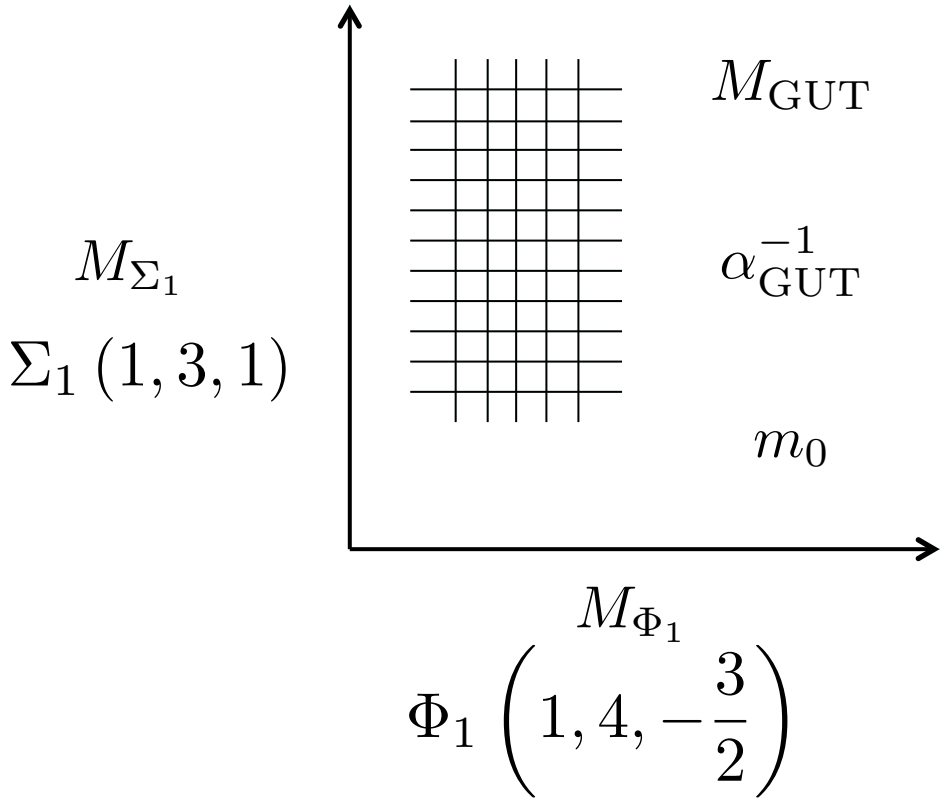
*I.D. and Shaikh Saad, Phys.Rev.D 101 (2020) 1, 015009, arXiv:1910.09008.

PARAMETER SPACE ANALYSIS *

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

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



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

PARAMETER SPACE ANALYSIS

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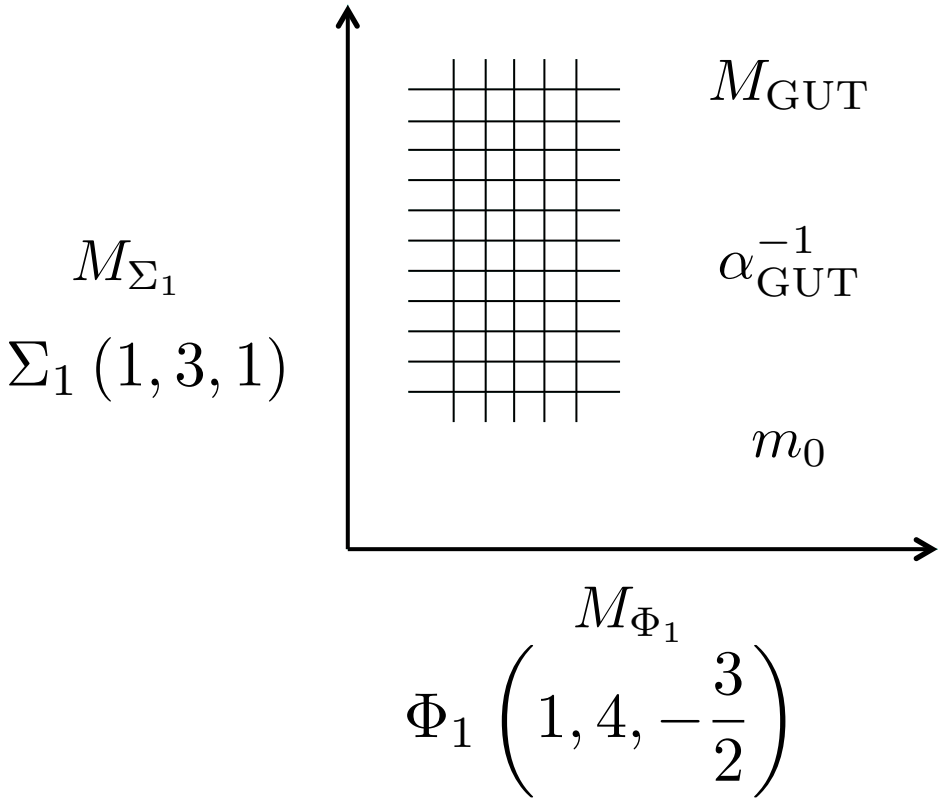

- FERMION MASS FIT*

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

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

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

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

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

PARAMETER SPACE ANALYSIS *

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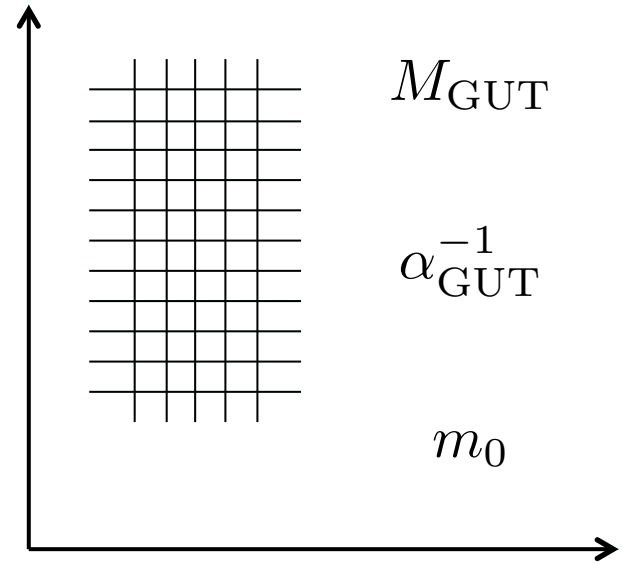


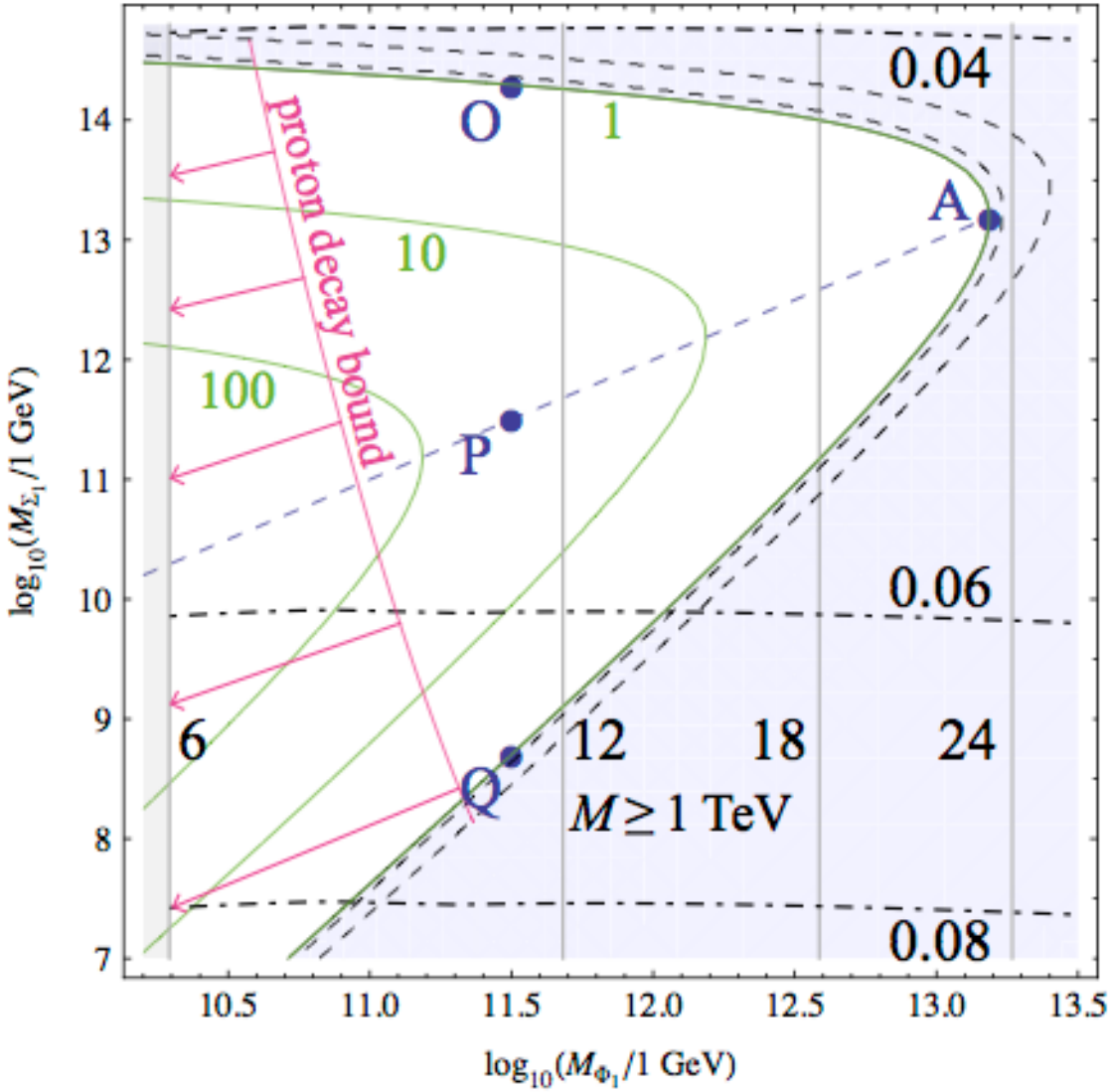
- FERMION MASS FIT

- PROTON DECAY ANALYSIS

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

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

PARAMETER SPACE ANALYSIS *



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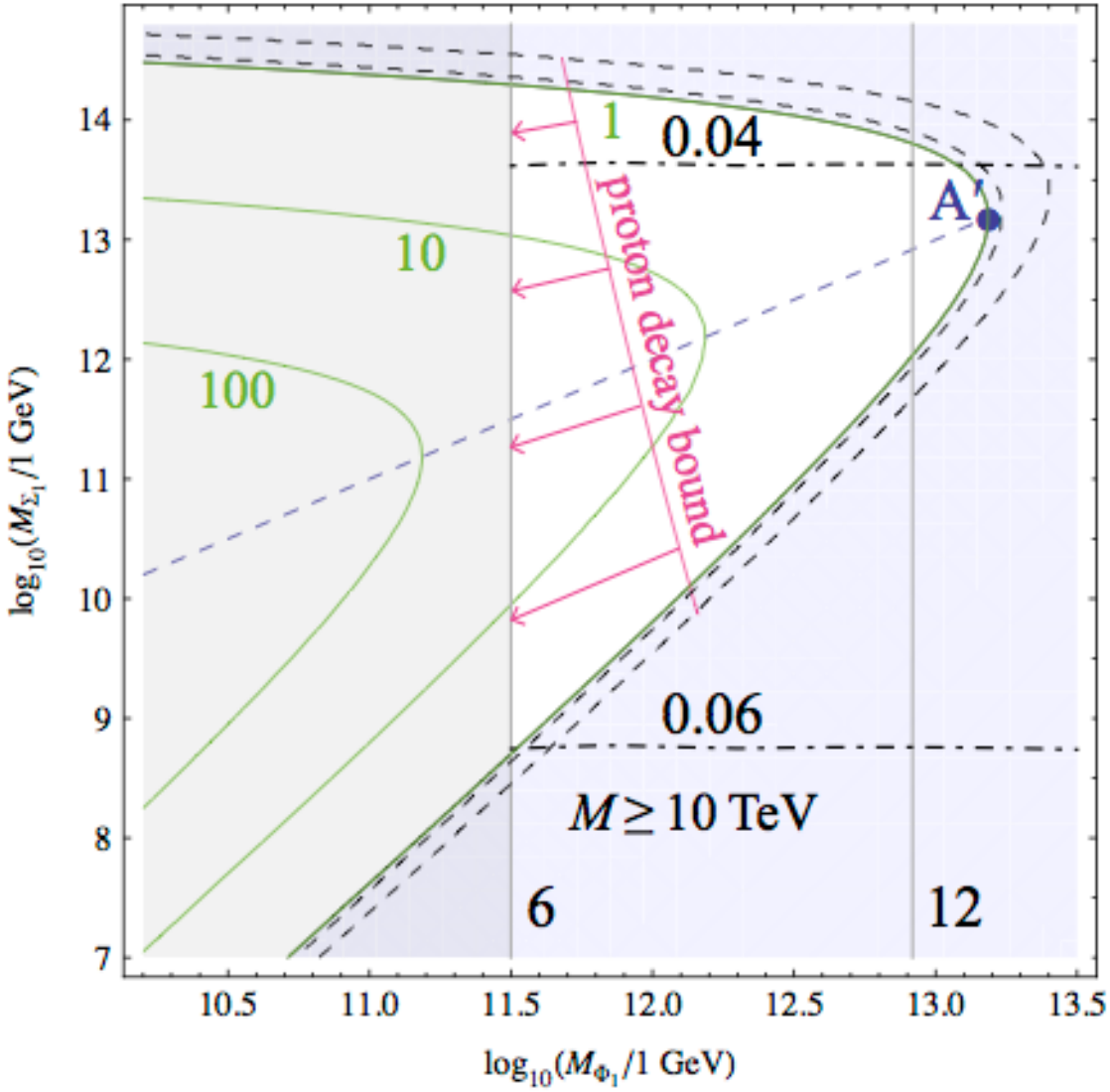

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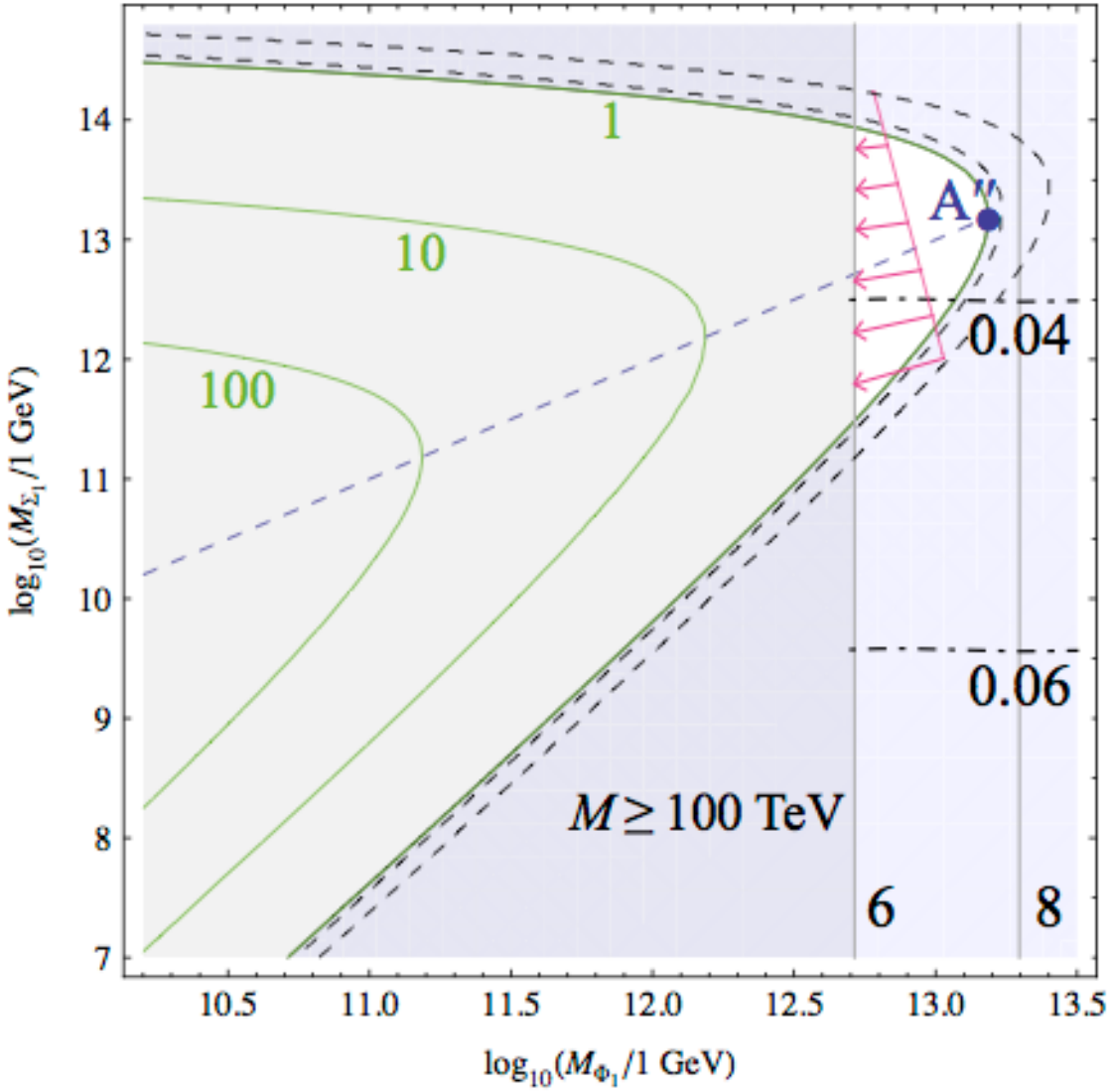

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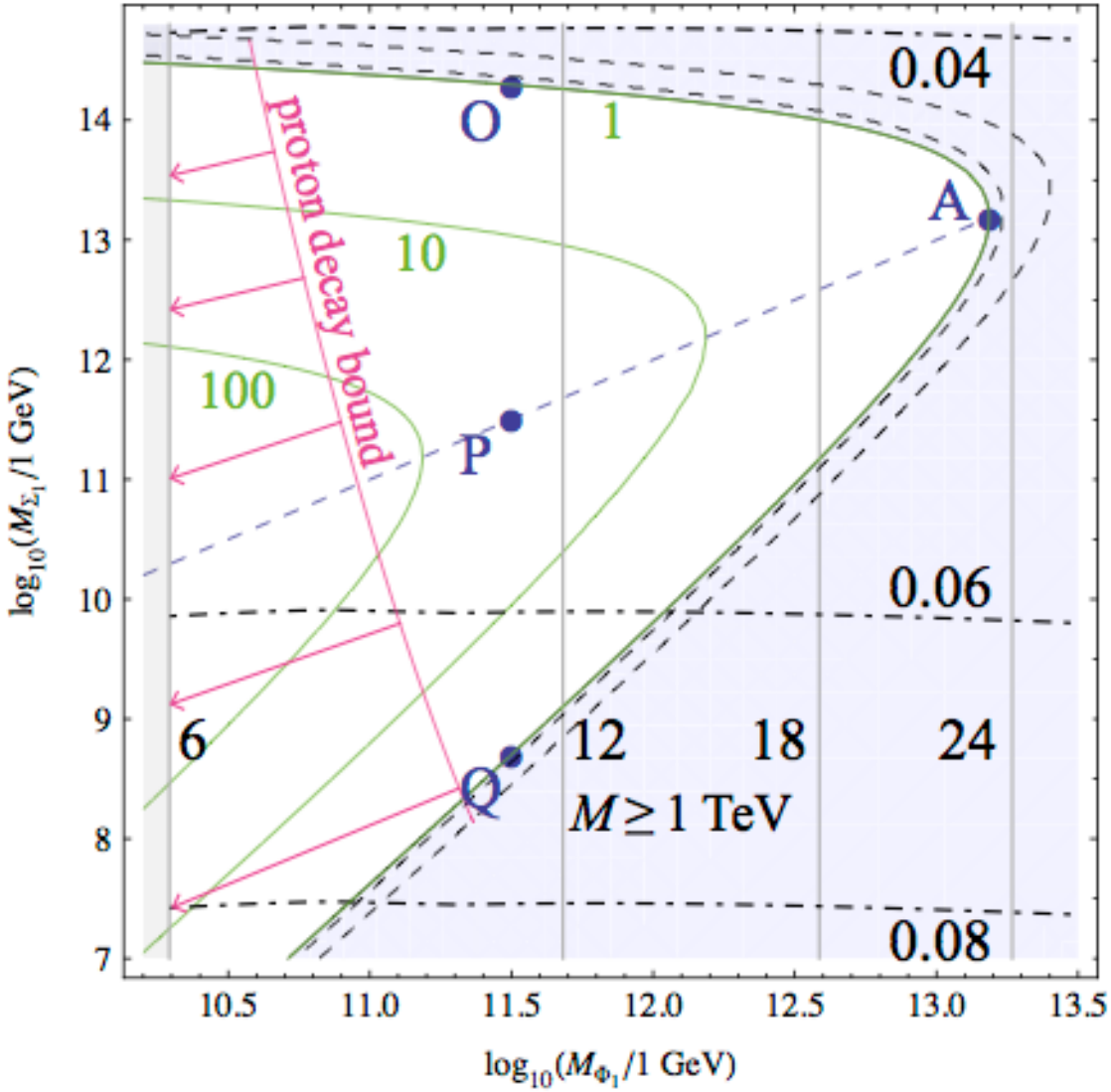

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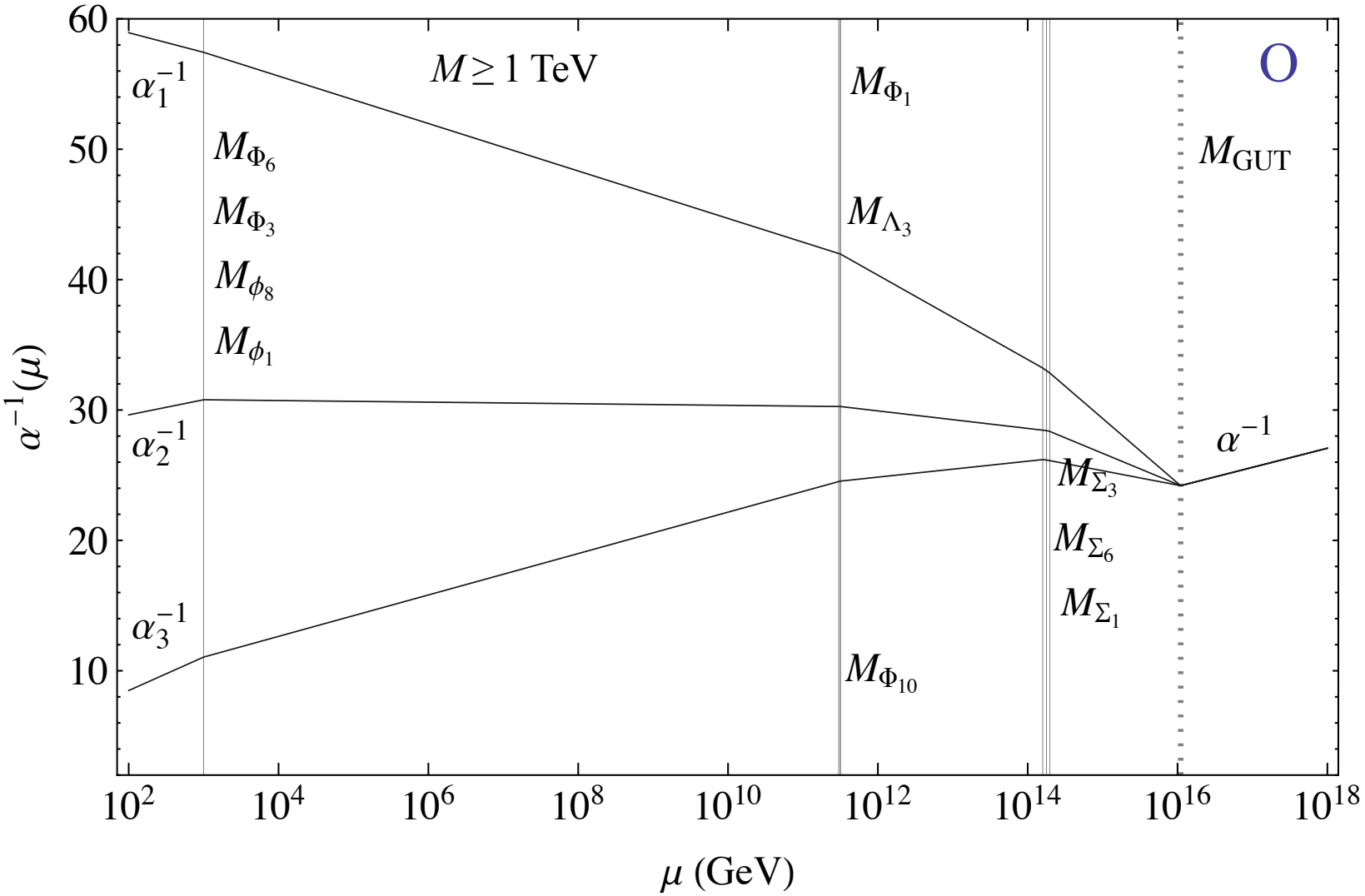

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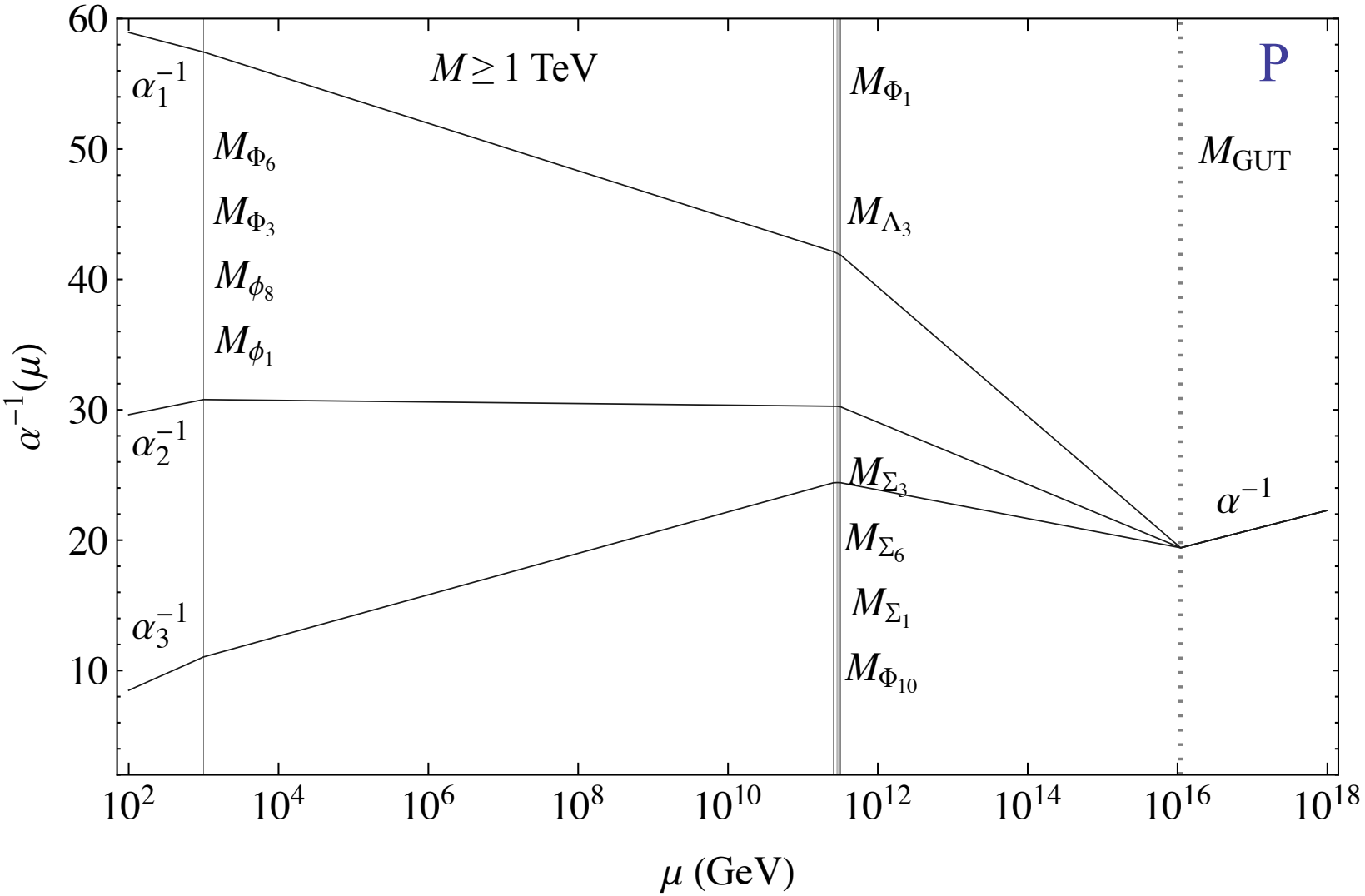

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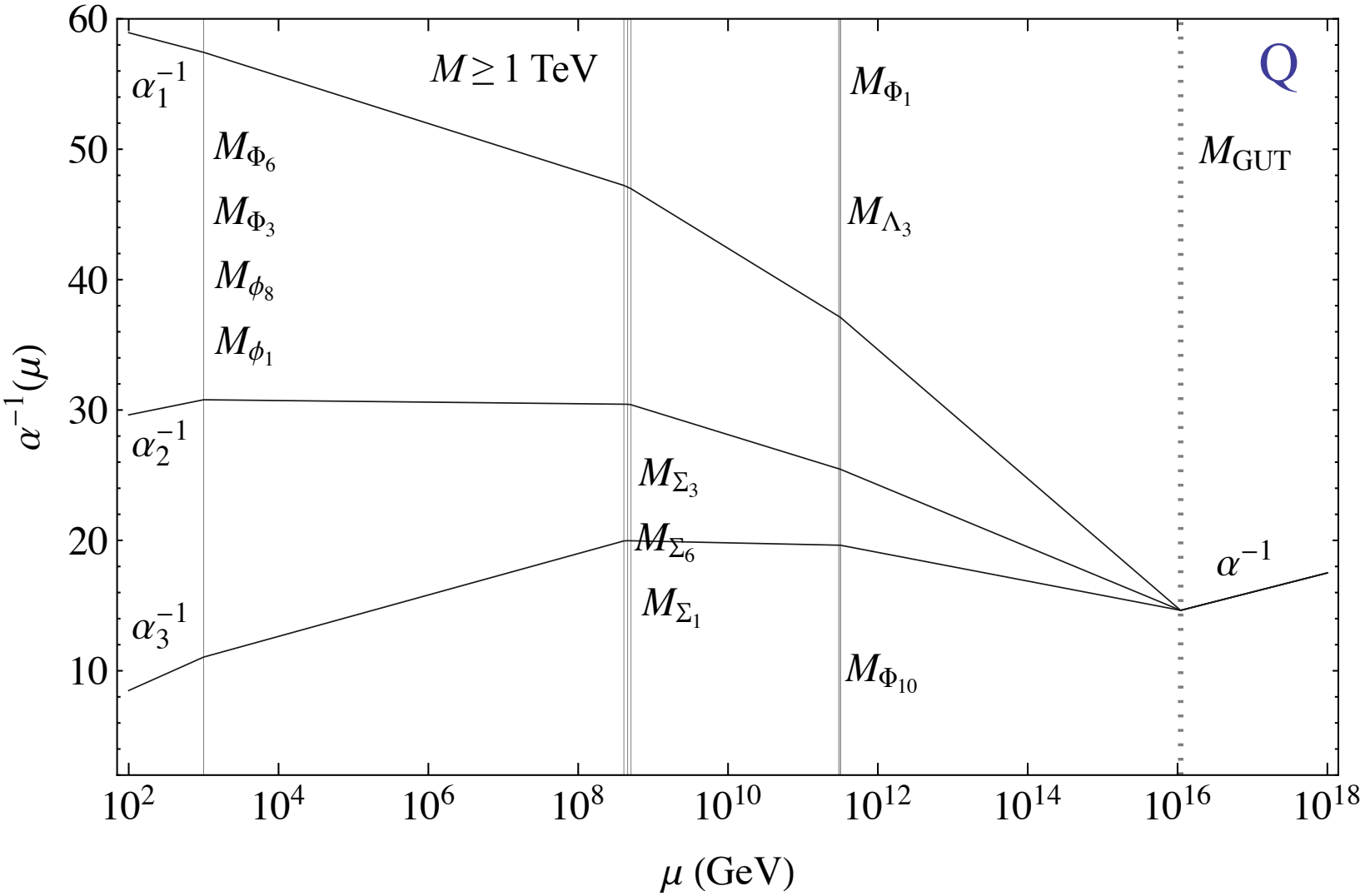

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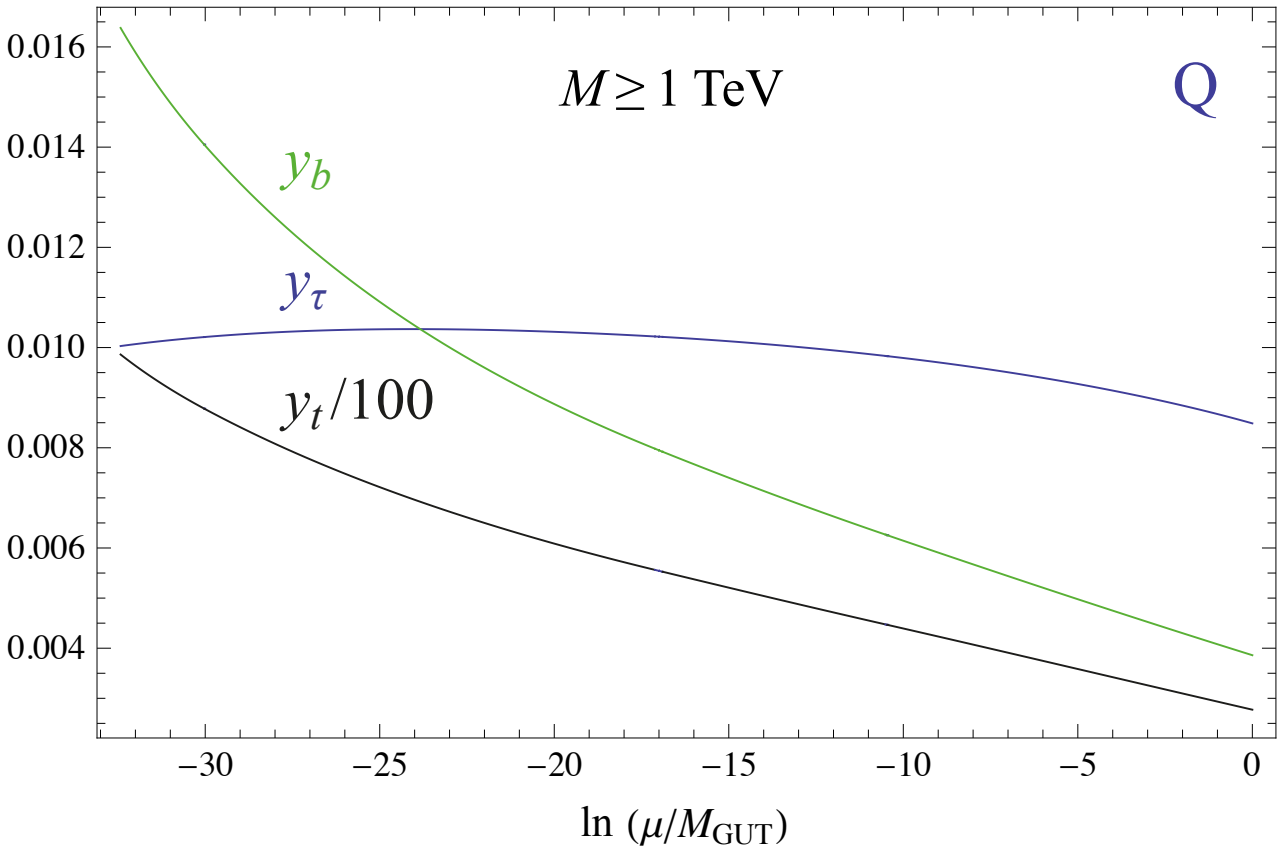

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CONCLUSIONS

PARTICLE CONTENT:

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

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
- NETRINO MASSES HAVE NORMAL ORDERING

CONCLUSIONS

- IF THE CURRENT PROTON DECAY LIMITSS ARE SATURATED, THERE ARE FOUR SCALAR MULTIPLETS AT 120 TeV.
- THESE MULTIPLETS 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 $p \rightarrow \pi^0 e^+$ 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.

THANK YOU

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