SU(5) GUT with Multi Vector Multiplets

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Minimal SU(5) GUT

- $SU(5)$ is a larger gauge group containing the Standard Model (SM) group $SU(3)_c \times SU(2)_L \times U(1)_Y$.
- The quarks and leptons of each generation are embedded into the chiral representations $\overline{\mathbf{5}}$ and $\mathbf{10}$ of $SU(5)$.

$$\overline{\mathbf{5}} = \begin{pmatrix} \overline{d}_R^1 \\ \overline{d}_R^2 \\ \overline{d}_R^3 \\ e_L \\ -\overline{\nu}_L \end{pmatrix}, \quad \mathbf{10} = \begin{pmatrix} 0 & \overline{u}_R^3 & -\overline{u}_R^2 & u_L^1 & d_L^1 \\ -\overline{u}_R^3 & 0 & \overline{u}_R^1 & u_L^2 & d_L^2 \\ \overline{u}_R^2 & -\overline{u}_R^1 & 0 & u_L^3 & d_L^3 \\ -u_L^1 & -u_L^2 & -u_L^3 & 0 & \overline{e}_R \\ -d_L^1 & -d_L^2 & -d_L^3 & -\overline{e}_R & 0 \end{pmatrix}$$

- The SM gauge fields G_μ, W_μ, B_μ and scalar field $H_{\rm SM}$ also embedded into $SU(5)$ representation.

$$A_\mu = \begin{pmatrix} \frac{1}{2}\lambda^a G_\mu^a - \sqrt{\frac{1}{15}} B_\mu & \frac{1}{\sqrt{2}} X_\mu^* \\ \frac{1}{\sqrt{2}} X_\mu^T & \frac{1}{2}\sigma_i W_\mu^i + \frac{1}{2}\sqrt{\frac{3}{5}} B_\mu \end{pmatrix}, \; H_5 = \begin{pmatrix} H_c \\ H_{\rm SM} \end{pmatrix}$$

- X_μ and H_c are new particles at GUT scale.
- A $\mathbf{24}$ representation Higgs Σ breaks $SU(5)$ to the SM via a vacuum expectation value.

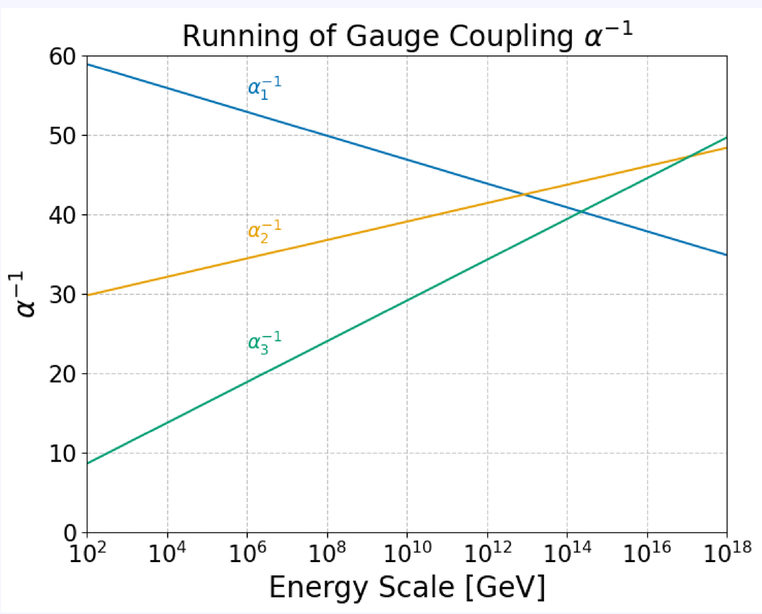
Problems of Minimal SU(5) GUT

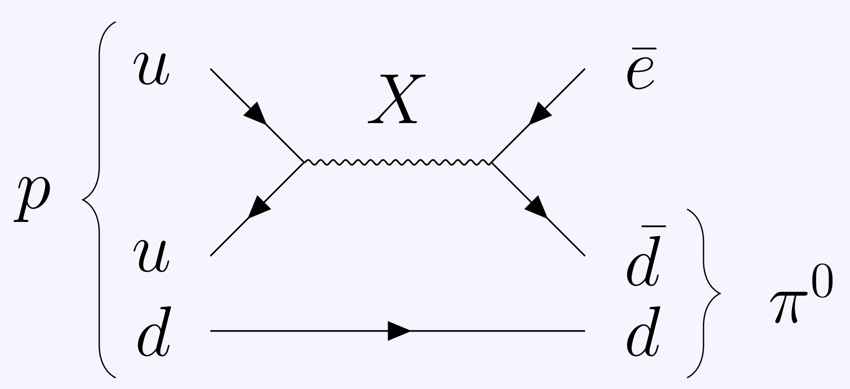
- **Gauge Coupling Non-Unification**
- **Too Short Proton Lifetime**

$$\tau(p \to \pi^0 + e^+) \simeq 5 \times 10^{26} \left(\frac{M_X/g_5}{10^{14}\ \mathrm{GeV}} \right)^4 \quad \text{[yrs]}$$

Already excluded by the current experimental limit

$$\tau(p \to \pi^0 + e^+) \geq 2.4 \times 10^{34} \quad \text{[yrs]}$$





Approach to the solution

- Supersymmetry
- Large representation fields
- **Multiple vector-like fermions** $\rightarrow$ **This Work!**

Introduce vector-like fermions

$$(\overline{\mathbf{5}},\, \mathbf{10}) \times 3 + (\mathbf{5},\, \overline{\mathbf{5}}) \times N_5 + (\mathbf{10},\, \overline{\mathbf{10}}) \times N_{10}$$

Unlike chiral fermions, vector-like fermions admit mass terms

$$\mathcal{L}_M = -\mathbf{10}(M_{10} + Y_{10}\Sigma^T)\overline{\mathbf{10}} - \overline{\mathbf{5}}(M_5 + Y_5\Sigma)\mathbf{5} + \mathrm{h.c.}\,,$$

$$M_{10,5} = M_0 \times O(1) = O(M_{\rm GUT}), Y_{10,5} = O(1)$$

$M_{10,5}, Y_{10,5}$ are $(N_{10,5}+3) \times N_{10,5}$ matrices,

$$\mathrm{rank}\big(M_{10} + Y_{10}\langle\Sigma^T\rangle\big) = N_{10}\,, \quad \mathrm{rank}(M_5 + Y_5\langle\Sigma\rangle) = N_5\,.$$

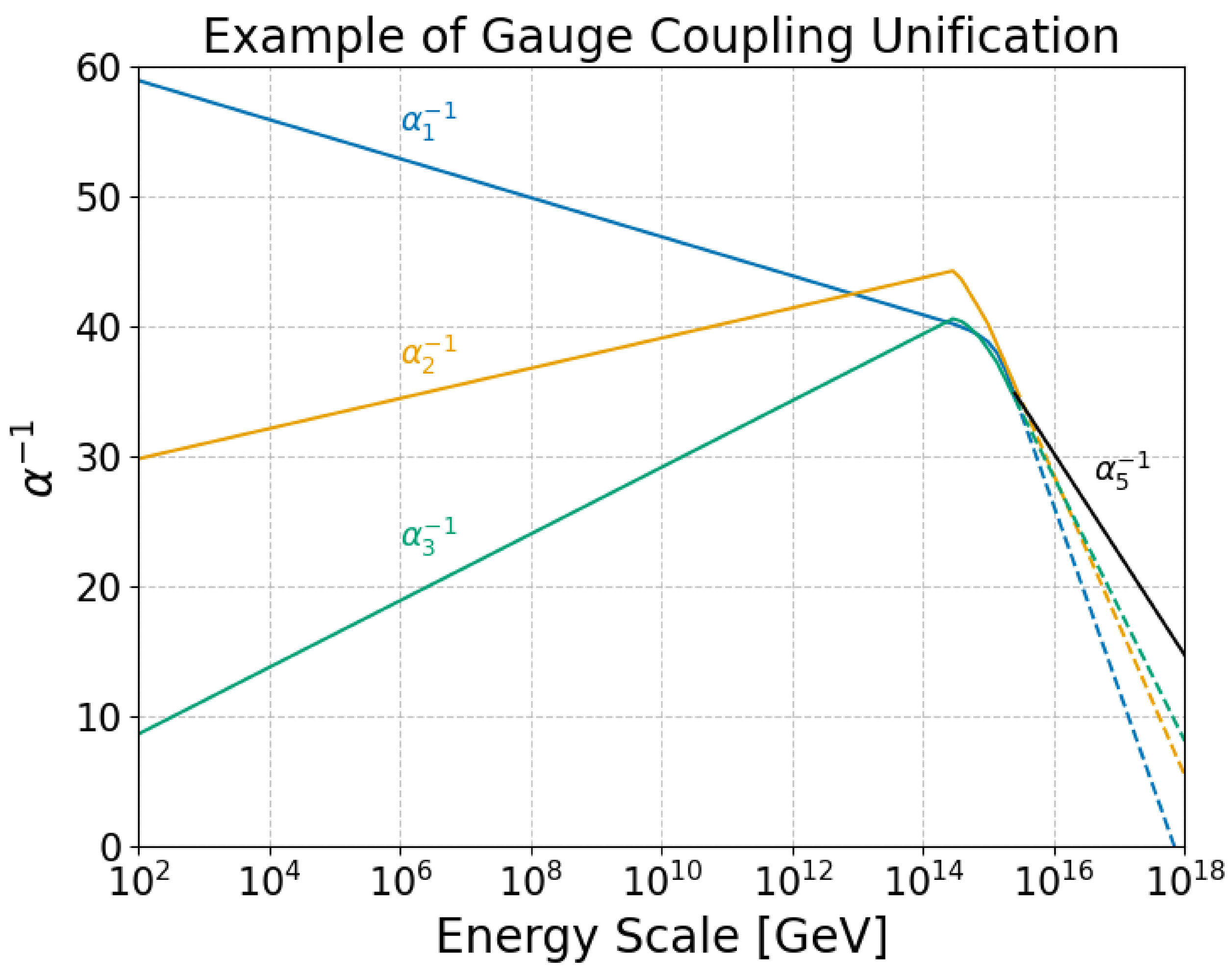
$\rightarrow$ Only 3-generations are massless.

Statistical Analysis

We take $M_{10,5}, Y_{10,5}$ to be complex random matrices(**a standard normal distribution**).

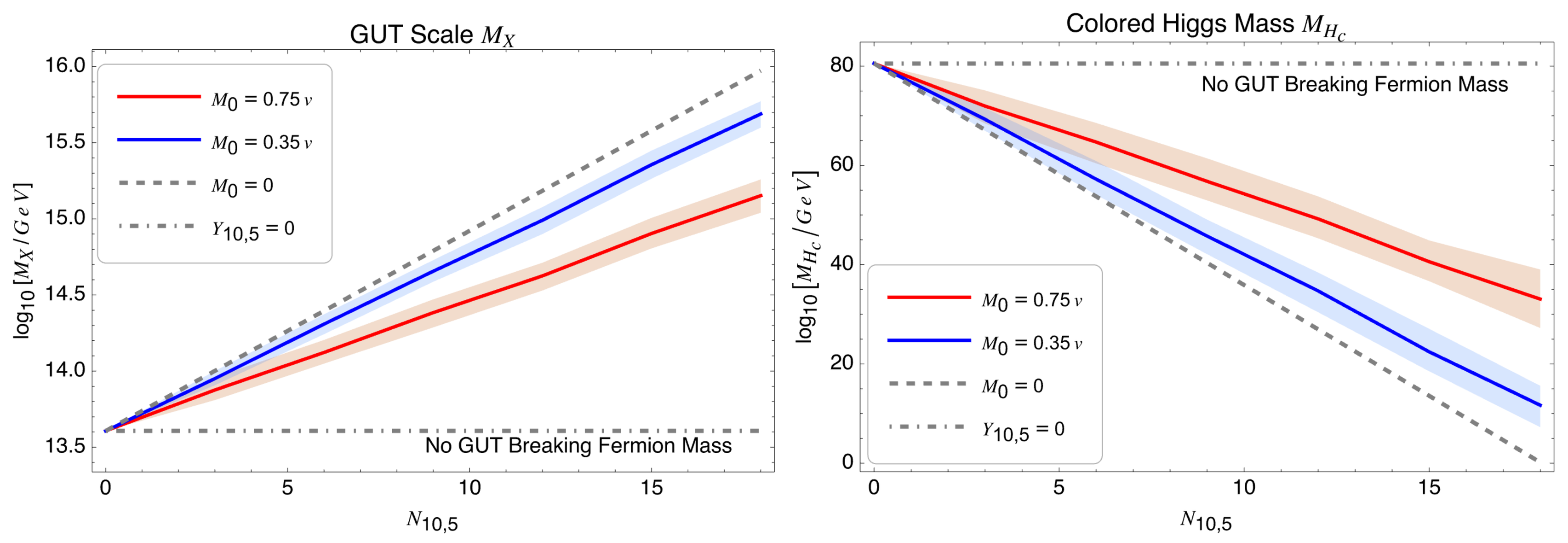
❶ Gauge Coupling Unification

Since the condition $\alpha_1^{-1} = \alpha_2^{-1} = \alpha_3^{-1}$ provides two independent equations, the unification can be realized by tuning the two parameters M_X and M_{H_c}.



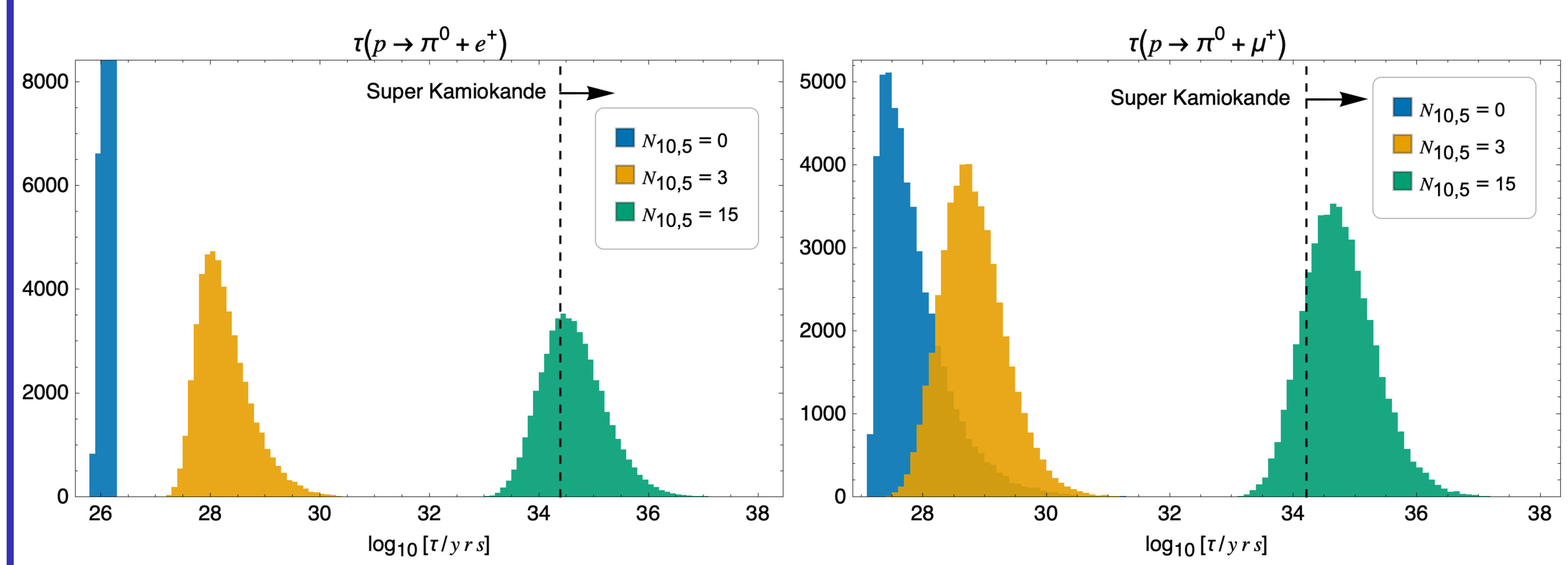
❷ X_μ, H_c Mass

Random fermion masses induce a spread in M_X and M_{H_c}, shown as 1σ.



❸ Proton Lifetime

$p \to \pi^0 + e^+$ and $p \to \pi^0 + \mu^+$ modes are close to the experimental limits and potentially observable.
Other modes far exceed the current limits and are not shown.



For $N \simeq 15$, both M_X and M_{H_c} are at the GUT scale, and the predicted proton lifetime is consistent with the current limits.

Summary and Future Work

- Presence of massive fermions can have large impacts on unification and proton decay.
- With $N \simeq 15$, proton decay is consistent with the experimental limits.
- In future work, I will explore **the effect of massive fermions in SO(10) or SUSY GUT models**.