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Fake GUT

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2. Minimal viable model

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SU(5) GUT (Grand Unified Theory)

- Force unification
- Charge quantization
- **SM fermions (f_{SM}) appear to have been unified into $\bar{5}$ and 10 of SU(5) : SU(5) nature**
- **Proton decay** ⟵ too early !

We want to explain SU(5) nature of f_{SM} while suppressing proton decay

Fake GUT

- **Fake GUT :** (M.Ibe, et al. (2019, 2022))
  - Another way which explain SU(5) nature of f_{SM} while suppressing proton decay
  - Even if q_{SM}'s and l_{SM}'s are not embedded into the same multiplets at the high energy,

    q_{SM}'s and l_{SM}'s form the apparently complete SU(5) multiplets at the low energy

ex : SU(5) Fake GUT

- Fermions : chiral $\bar{5}, 10$ **vector-like** $\mathbf{5_H, \bar{5}_H}$

general feature of the fake GUT

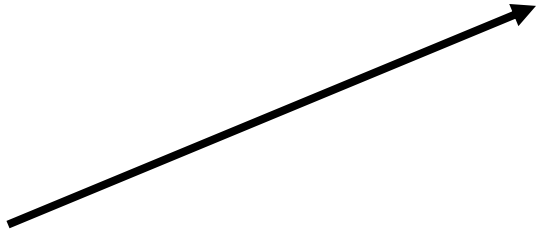
ex : SU(5) Fake GUT

- Fermions : chiral $\bar{5}, 10$ **vector-like** $\mathbf{5}_H, \bar{\mathbf{5}}_H$

In the SU(5) GUT, all f_{SM}'s are contained in $\bar{5}$ and 10.

ex : SU(5) Fake GUT

- Fermions : chiral $\bar{5}, 10$ **vector-like** $\mathbf{5}_H, \bar{\mathbf{5}}_H$



In the fake GUT, f_{SM}'s can be contained in vector-like fermions.

ex : SU(5) Fake GUT

- Fermions : chiral $\bar{5}, 10$ **vector-like** $5_H, \bar{5}_H$
- Extreme case

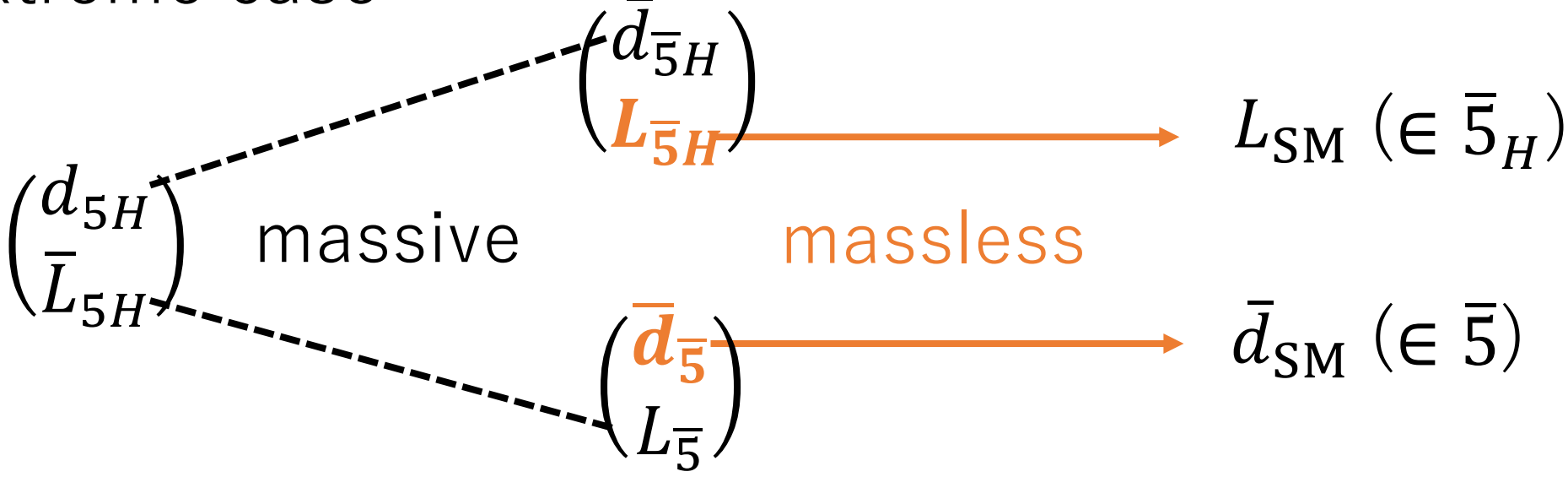
$$5_H = \begin{pmatrix} d_{5H} \\ \bar{L}_{5H} \end{pmatrix}$$

$$\bar{5}_H = \begin{pmatrix} \bar{d}_{\bar{5}H} \\ L_{\bar{5}H} \end{pmatrix}$$

$$\bar{5} = \begin{pmatrix} \bar{d}_{\bar{5}} \\ L_{\bar{5}} \end{pmatrix}$$

ex : SU(5) Fake GUT

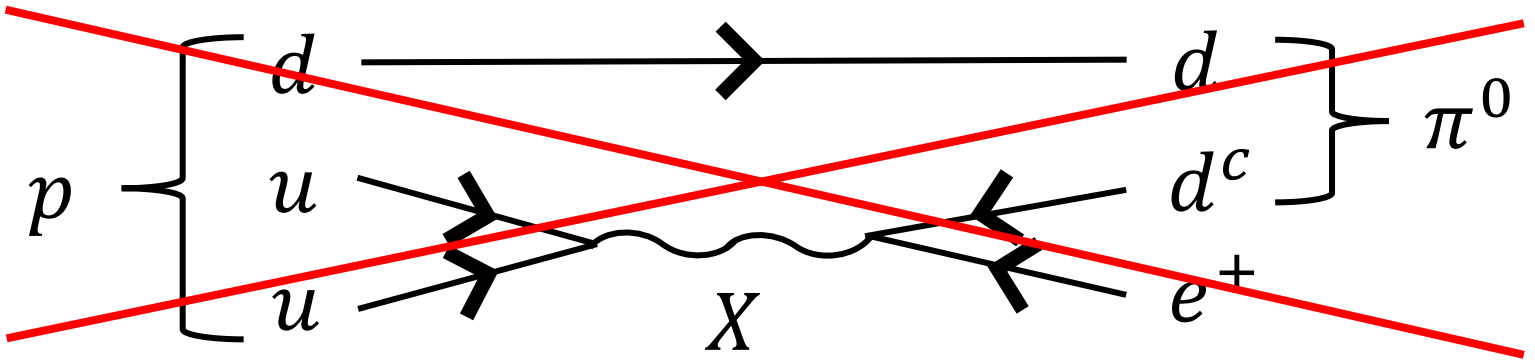
- Fermions : chiral $\bar{5}, 10$ **vector-like** $\mathbf{5_H, \bar{5}_H}$
- Extreme case



- L_{SM} and $\bar{d}_{\mathrm{SM}}$ form $\bar{5}$ even if their origins are different
- This is achieved as long as chiral SU(5) fermions exist

ex : SU(5) Fake GUT

- If origins of L_{SM} and $\bar{d}_{\mathrm{SM}}$ are different,



- Generally, $L_{\mathrm{SM}}\,(\bar{d}_{\mathrm{SM}}) = \cos\theta \cdot L_{\bar{5}H}\,(\bar{d}_{\bar{5}}) - \sin\theta \cdot L_{\bar{5}}\,(\bar{d}_{\bar{5}H})$
- Proton decay is suppressed by mixing angles

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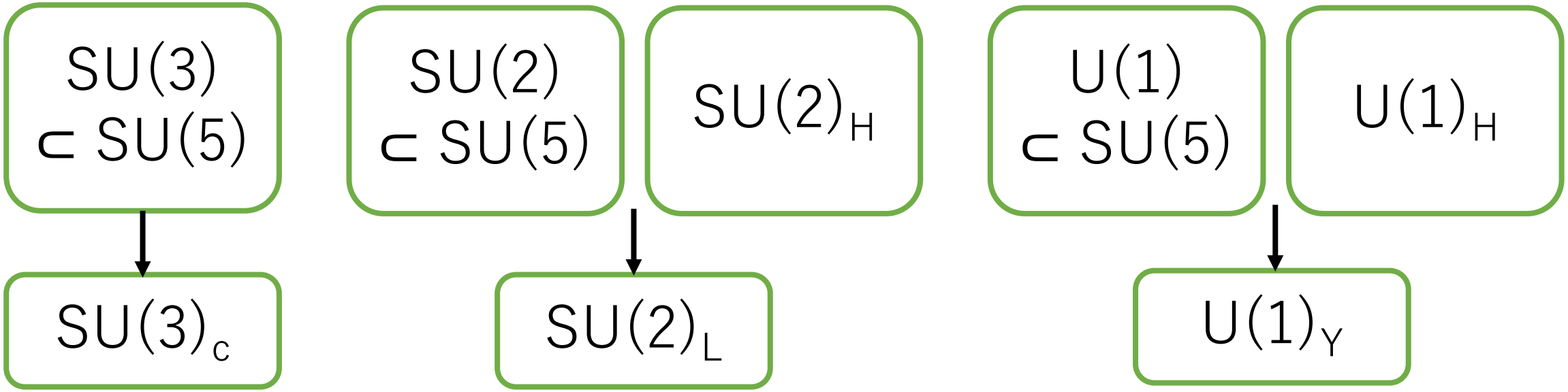
Fermions in the $SU(5) \times U(2)_H$ model

- Chiral fermions $\bar{5}, 10$ $(\times 3)$: SU(5) multiplets
- Vector-like fermions $L_H, \bar{L}_H$ $(\times 3)$: $SU(2)_H$ doublets

  $e_H, \bar{e}_H$ $(\times 3)$: $SU(2)_H$ singlets

- SM quarks $\in \bar{5}, 10$
- SM leptons $\approx L_H, \bar{e}_H$

Breaking of $SU(5) \times U(2)_H$ Symmetry



As a result,

$L_{\bar{5}}$ and L_H ($\bar{e}_{10}$ and $\bar{e}_H$) have same charges as L_{SM} ($\bar{e}_{\mathrm{SM}}$)

SM fermions

- Quark components (one generation)

$$q_{\mathrm{SM}} = q_{\bar{5}\ \mathrm{or}\ 10}$$

- Lepton components (one generation)

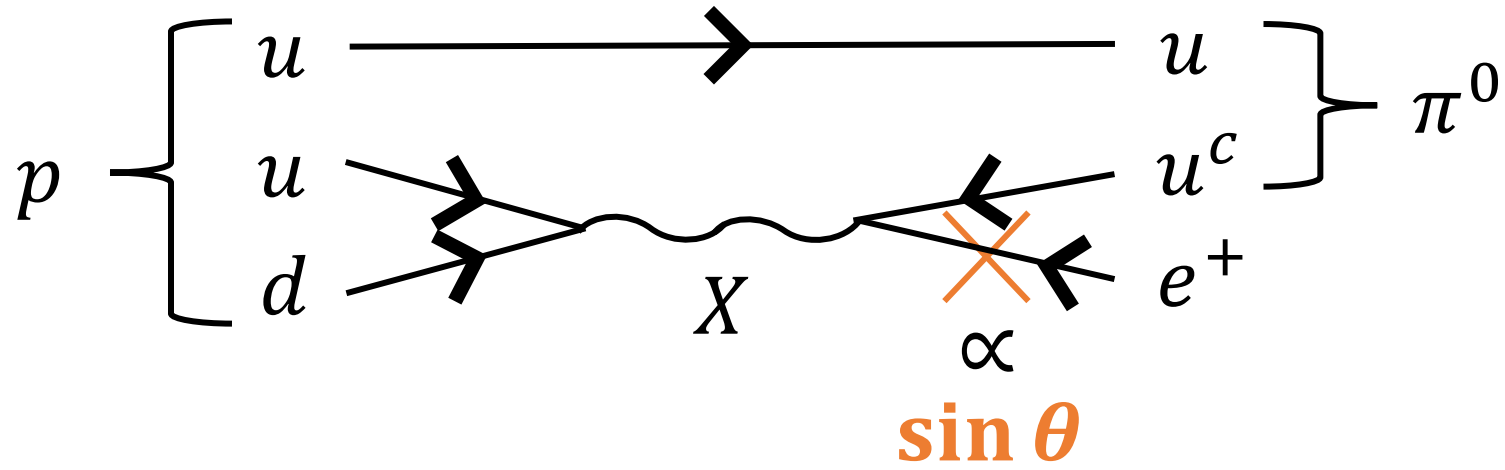
$$\begin{pmatrix} L_{\bar{5}} \\ L_H \end{pmatrix} = \begin{pmatrix} \cos\theta_L & \boldsymbol{-\sin\theta_L} \\ \sin\theta_L & \cos\theta_L \end{pmatrix} \begin{pmatrix} L_M \\ \boldsymbol{L_{\mathrm{SM}}} \end{pmatrix}, \quad \begin{pmatrix} \bar{e}_{10} \\ \bar{e}_H \end{pmatrix} = \begin{pmatrix} \cos\theta_{\bar{e}} & \boldsymbol{-\sin\theta_{\bar{e}}} \\ \sin\theta_{\bar{e}} & \cos\theta_{\bar{e}} \end{pmatrix} \begin{pmatrix} \bar{e}_M \\ \boldsymbol{\bar{e}_{\mathrm{SM}}} \end{pmatrix}$$

Protons can decay due to

$$\begin{cases} L_{\bar{5}} = \boldsymbol{-\sin\theta_L} \times L_{\mathrm{SM}} + \cdots \\ \bar{e}_{10} = \boldsymbol{-\sin\theta_{\bar{e}}} \times \bar{e}_{\mathrm{SM}} + \cdots \end{cases}$$

Proton decay

- Diagram ($p \to \pi^0 e^+$)



- Lifetime ($p \to \pi^0 e^+$)

$$\tau(p \to \pi^0 e^+) \cong 10^{26} \frac{1}{\sin^2\theta} \left(\frac{M_X / g_5}{10^{14}\ \mathrm{GeV}} \right)^4 \ \mathrm{yrs}$$

Multiple flavors

- Conventional SU(5) GUT

  q_{SM}'s and l_{SM}'s of same gen $\longrightarrow$ same SU(5) multiplets

  Decay into same gen $\longrightarrow$ ex. $\tau(p \to \pi^0 e^+) < \tau(p \to \pi^0 \mu^+)$

- Fake GUT

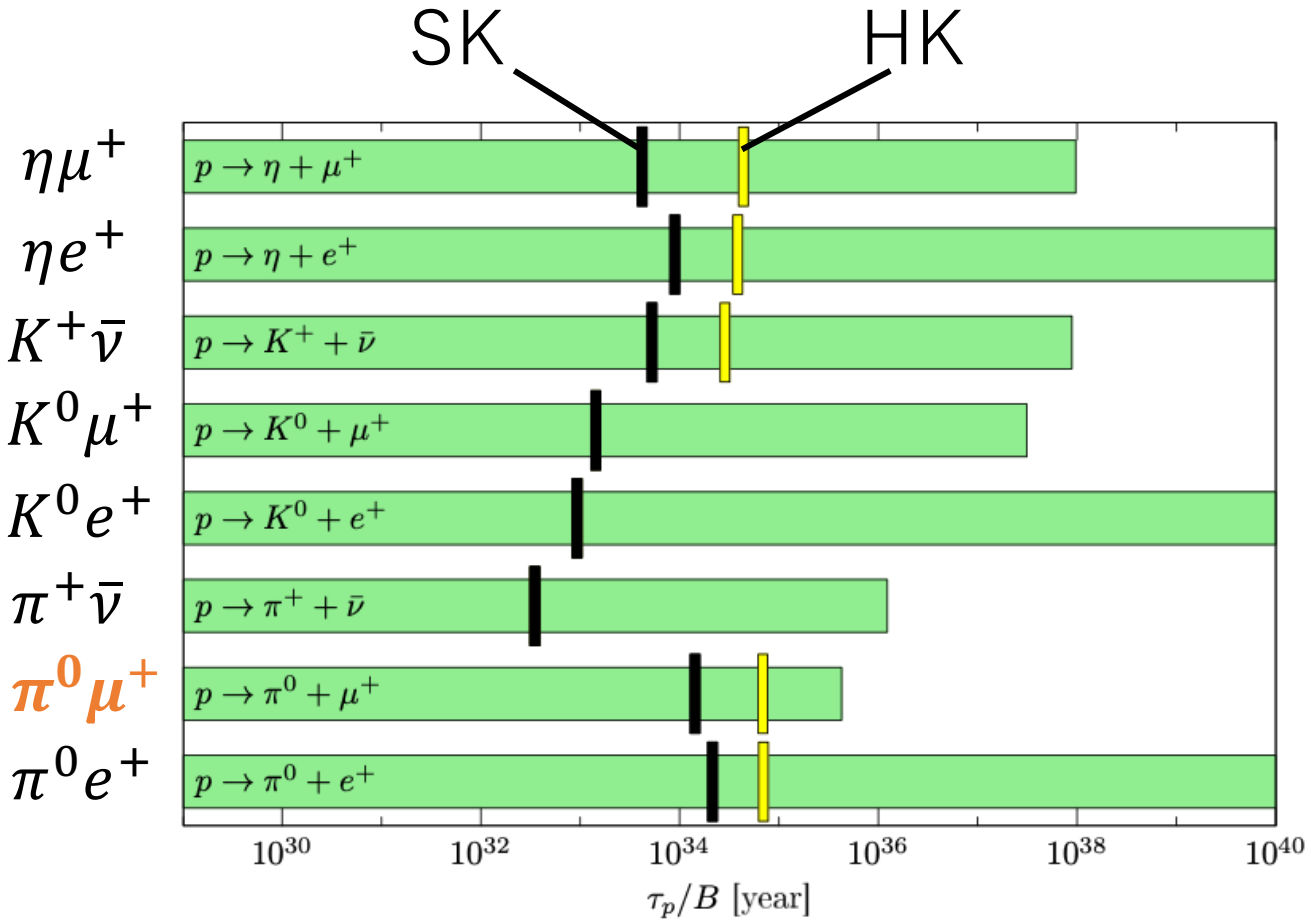
  q_{SM}'s and l_{SM}'s are contained in different multiplets

  One situation :

$$\begin{cases} L_{\bar{5},1} = -\sin\theta \times \boldsymbol{L_{\mathrm{SM},\mu}} + \cdots \\ \bar{e}_{10,1} = -\sin\theta \times \boldsymbol{\bar{e}_{\mathrm{SM},\mu}} + \cdots \end{cases}$$

Proton decay (flavor mixing)

$$\begin{bmatrix} L_{\bar{5},1} = -\sin\theta \times \boldsymbol{L_\mu} + \cdots \\ \bar{e}_{10,1} = -\sin\theta \times \boldsymbol{\bar{e}_\mu} + \cdots \end{bmatrix}$$



The fake GUT can make the different prediction than the conventional GUT

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3. Summary

- Fake GUT explains SU(5) nature of SM fermions while suppressing proton decay

- The predictions of the nucleon decay are different from those in the conventional GUT

BACK UP

Definition of the fake GUT

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- Cartan of SU(5) ⊃ Cartan of ($SU(3)_c$, $SU(2)_L$, $U(1)_Y$)
- Fermions

  Chiral $\bar{5}, 10$

  Vector-like $H, \bar{H}$ (under SU(5) × H)
- (Some of $SU(3)_c$, $SU(2)_L$ and $U(1)_Y$ may be diagonal subgroup of SU(5) × H)

Definition of the fake GUT

- SU(5) × H —Symmetry breaking→ SM

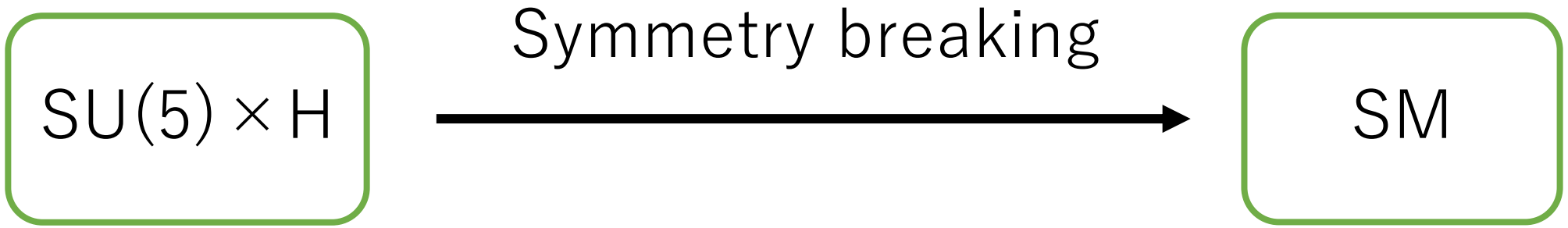
- Fermions

  Chiral fermion $\bar{5}, 10$

  In the SU(5) GUT, all f_{SM}'s are contained in $\bar{5}$ and 10.

  Vector-like fermion $H, \bar{H}$

Definition of the fake GUT

- 

- Fermions

  Chiral $\bar{5}, 10$

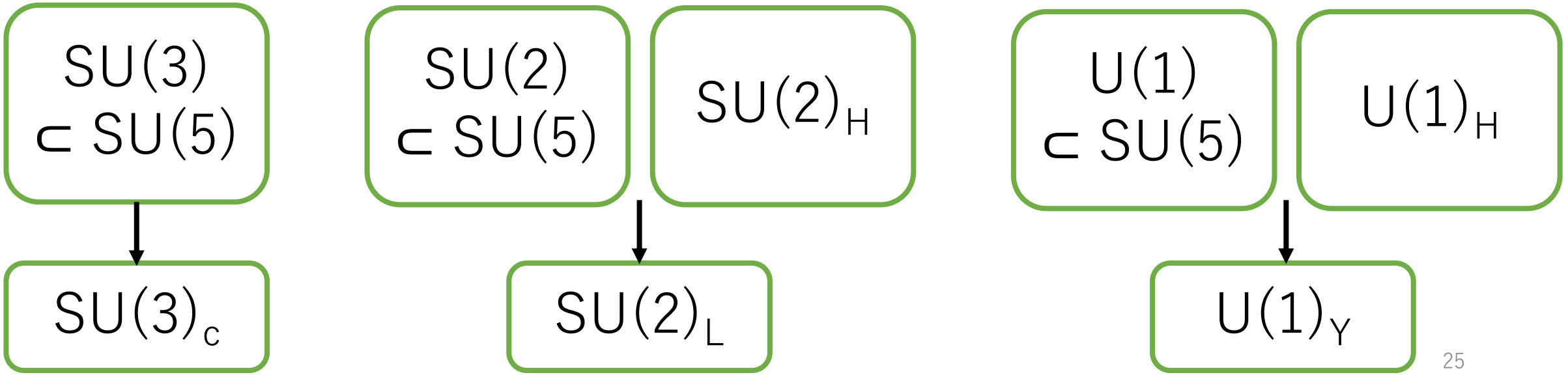
  Vector-like $H, \bar{H}$

In the fake GUT, f_{SM}'s can be contained in vector-like fermions.

Scalar in the $SU(5) \times U(2)_H$ model

- $\phi_2 : (5, 2, -1/2)$

$$\langle \phi_2 \rangle = \begin{pmatrix} \underbrace{0 & 0 & 0}_{SU(3)} & v_2 & 0 \\ 0 & 0 & 0 & \underbrace{0 & v_2}_{SU(2)} \end{pmatrix} \Big\} SU(2)_H$$



Origin of SM fermions

- Lagrangian

$$\mathcal{L} = m_L\, L_H\, \bar{L}_H + \lambda_L\, \bar{5}\, \phi_2 \bar{L}_H + m_e\, e_H\, \bar{e}_H + \frac{\lambda_E}{\Lambda}\, e_H\, \phi_2^\dagger \phi_2^\dagger\, 10$$

- L components (one generation)

$$\bar{L}_H \begin{pmatrix} \lambda_L v_2 & m_L \end{pmatrix} \begin{pmatrix} L_{\bar{5}} \\ L_H \end{pmatrix} = \bar{L}_H \begin{pmatrix} M_L & 0 \end{pmatrix} \begin{pmatrix} L_M \\ L_{\mathrm{SM}} \end{pmatrix}$$

$$\begin{pmatrix} L_{\bar{5}} \\ L_H \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} L_M \\ L_{\mathrm{SM}} \end{pmatrix} \quad \tan\theta = \frac{m_L}{\lambda_L\, v_2}$$

  - The same argument is made for the $\bar{e}$ conponents

$\mathbf{SU(5)\times U(2)_H}$ model

Yukawa interactions

We consider a case one SM Higgs remains in the low energy.

Scalar containing the SM Higgs

$H_5 : (5, 1, 0\,)$ $\qquad H_5 = \begin{pmatrix} h_5^{color} \\ h_5^{SM} \end{pmatrix}$

$H_2 : (1, 2, 1/2\,)$ $\qquad H_2 = h_2^{SM}$

Higgs mixing term $\qquad \mathcal{L}_{52\,mix} = \mu_{mix} H_2 \phi_2 H_5^* + h.c.$

$$h^{SM} = \cos\theta_h\, h_2^{SM} - \sin\theta_h\, h_5^{SM}$$

$\mathbf{SU(5)\times U(2)_H}$ model

Yukawa interactions

$$\mathcal{L}_{YQ} = -(y_5)_{ij}\,\bar{5}_i\,10_j\,H_5^* - (y_{10})_{ij}\,10_i\,10_j\,H_5 + h.c.$$

$$\mathcal{L}_{YL} = -(y_{LE})_{ij}\,L_{Hi}\,\bar{e}_{Hj}\,H_2^* + h.c.$$

$$(y_u^{SM})_{ij} = -\sin\theta_h\,(y_{10})_{ij}$$

$$(y_d^{SM})_{ij} = -\sin\theta_h\,(y_5)_{ij}$$

$$(y_e^{SM})_{ij} = \cos\theta_h\,(y_{LE})_{ij} + \mathcal{O}(\theta_L\theta_E)\sin\theta_h\,(y_5)_{ij}$$

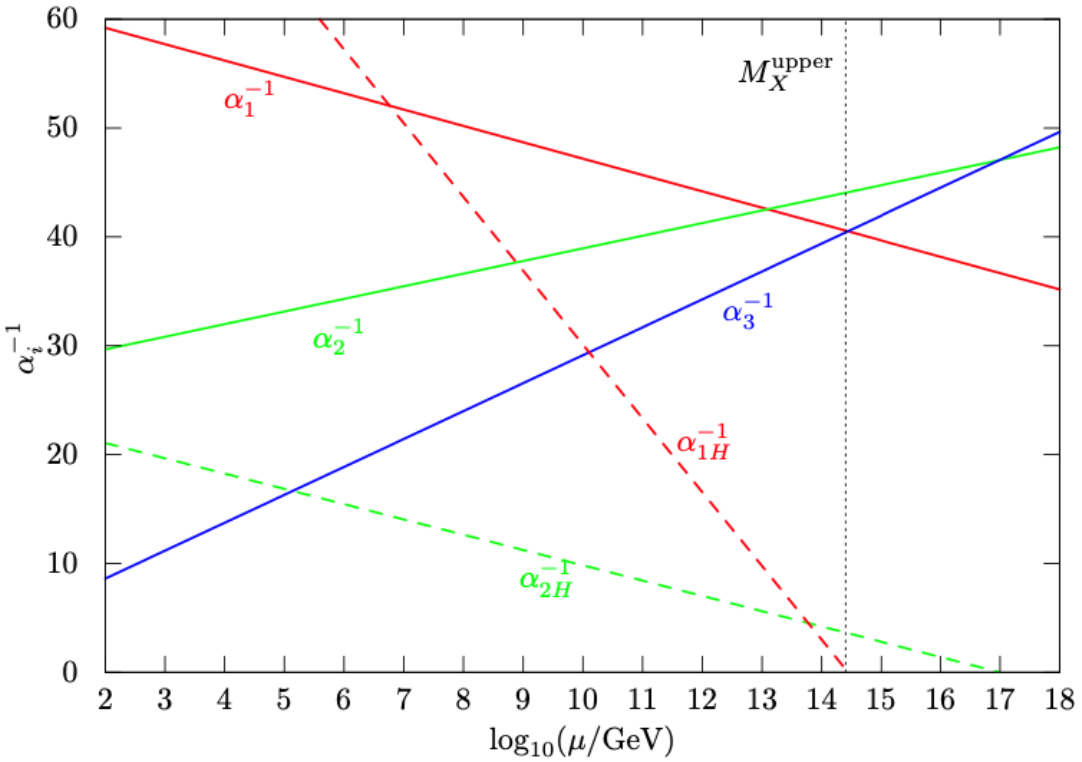
Gauge couplings

Gauge couplings

$$\alpha_1^{-1}(M_X) = \alpha_5^{-1}(M_X) + \frac{3}{5}\alpha_{1H}^{-1}(M_X)$$

$$\alpha_2^{-1}(M_X) = \alpha_5^{-1}(M_X) + \alpha_{2H}^{-1}(M_X)$$

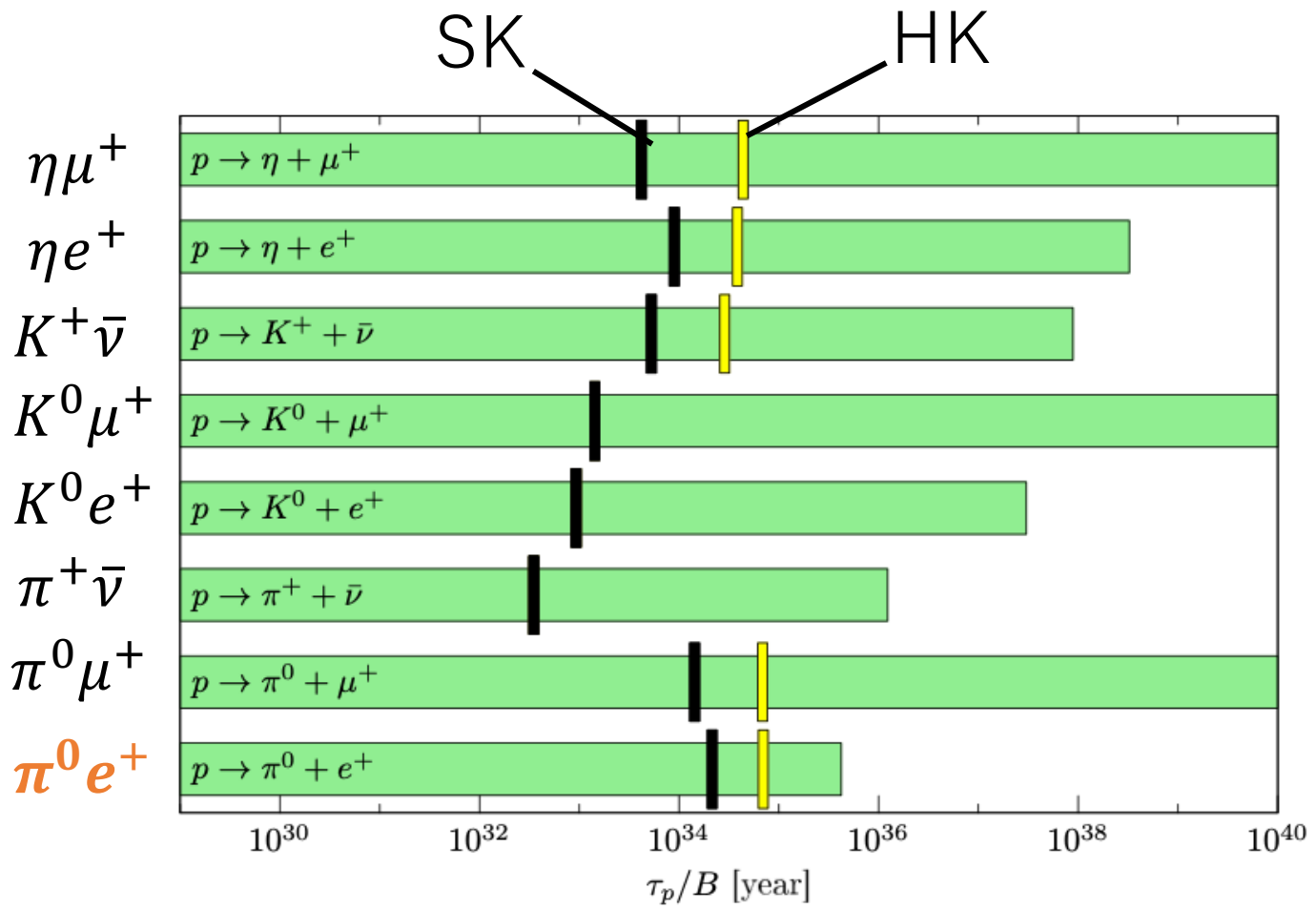
$$\alpha_3^{-1}(M_X) = \alpha_5^{-1}(M_X)$$



$$M_X^{\mathrm{upper}} \cong 10^{14.4}\ \mathrm{GeV}$$

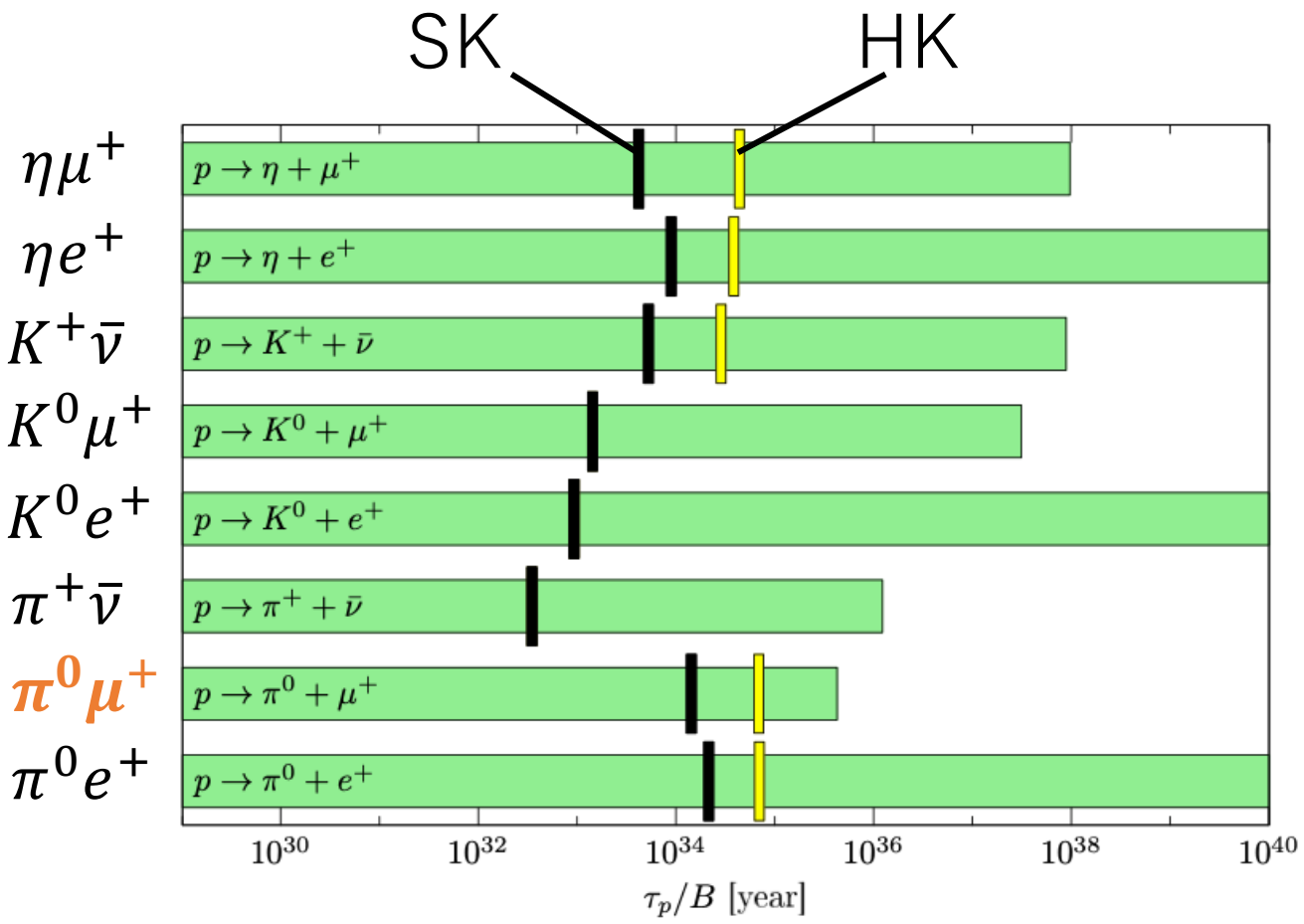
Proton decay (flavor mixing)

$$\begin{bmatrix} L_{\bar{5},1} = -\sin\theta \times \boldsymbol{L_e} + \cdots \\ \bar{e}_{10,1} = -\sin\theta \times \boldsymbol{\bar{e}_e} + \cdots \end{bmatrix}$$



Proton decay (flavor mixing)

$$\begin{bmatrix} L_{\bar{5},1} = -\sin\theta \times \boldsymbol{L_\mu} + \cdots \\ \bar{e}_{10,1} = -\sin\theta \times \boldsymbol{\bar{e}_\mu} + \cdots \end{bmatrix}$$



Proton decay (flavor mixing)

$$\begin{bmatrix} L_{\bar{5},2} = -\sin\theta \times \boldsymbol{L_e} + \cdots \\ \bar{e}_{10,2} = -\sin\theta \times \boldsymbol{\bar{e}_e} + \cdots \end{bmatrix}$$