OBSERVABLE PROTON DECAY IN FLIPPED SU(5)

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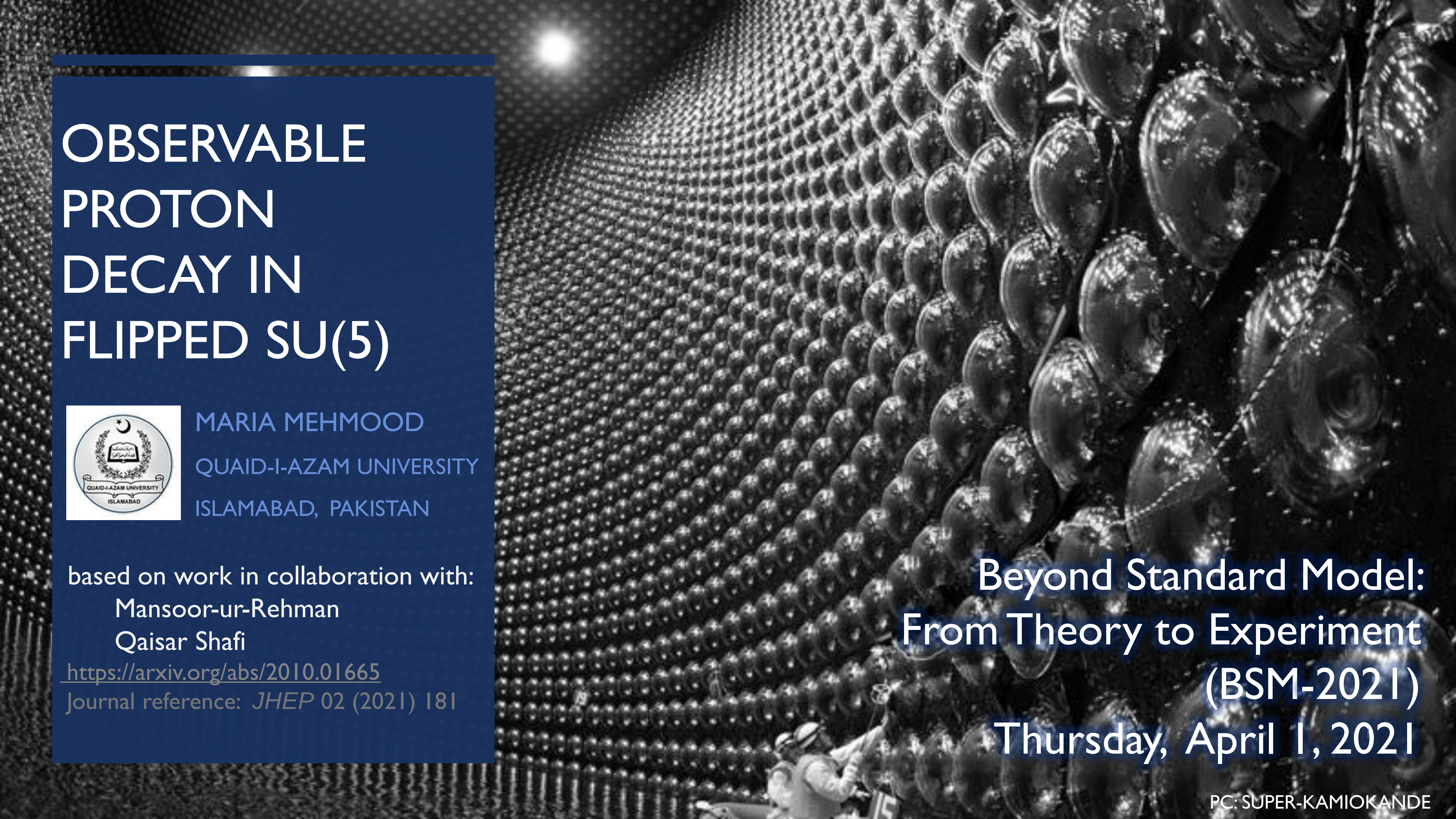
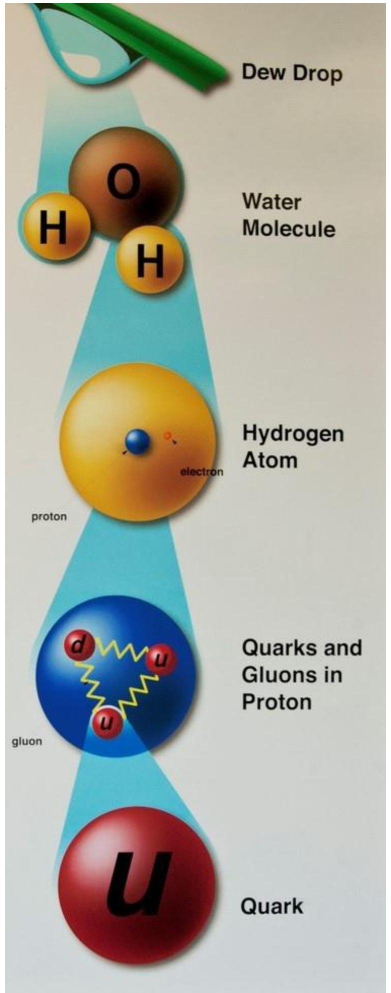
https://arxiv.org/abs/2010.01665
Journal reference: *JHEP* 02 (2021) 181

Beyond Standard Model:
From Theory to Experiment
(BSM-2021)
Thursday, April 1, 2021

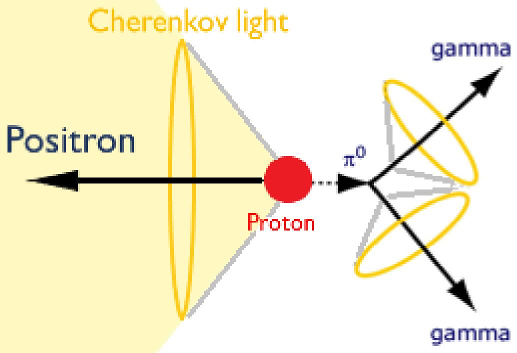


PC: SUPER-KAMIOKANDE

OVERVIEW



- Model: Flipped SU(5)
- Proton Decay in Flipped SU(5)
- Comparison of Flipped SU(5) and SU(5)
- Summary



MODEL: FLIPPED SU(5)

- Gauge group: SU(5) x $U(1)_X$
- Global $U(1)_R$ symmetry and $\mathbb{Z}_2$ matter parity
- Superpotential:

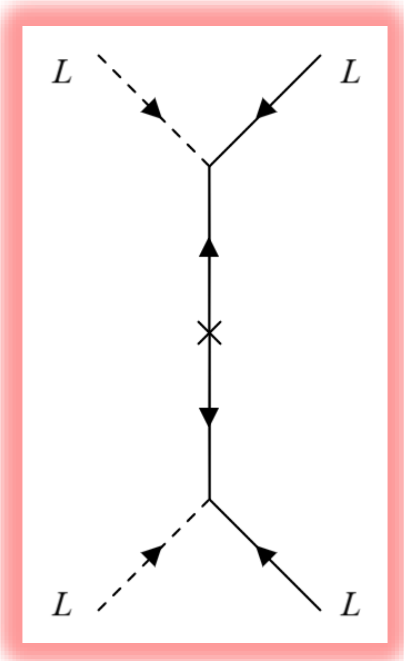
$$
\begin{aligned}
W = {} & \kappa S \left(10^1_H \overline{10}^{-1}_H - M^2 \right) \\
& + \frac{\lambda}{8} 10^1_H 10^1_H 5^{-2}_h + \frac{\bar{\lambda}}{8} \overline{10}^{-1}_H \overline{10}^{-1}_H \bar{5}^2_h \\
& + \frac{1}{8} y^{(d)}_{ij} 10^1_i 10^1_j 5^{-2}_h + y^{(u,\nu)}_{ij} 10^1_i \bar{5}^{-3}_j \bar{5}^2_h + y^{(e)}_{ij} 1^5_i \bar{5}^{-3}_j 5^{-2}_h + W_{HN}
\end{aligned}
$$

- W_{HN} : Inverse seesaw mechanism

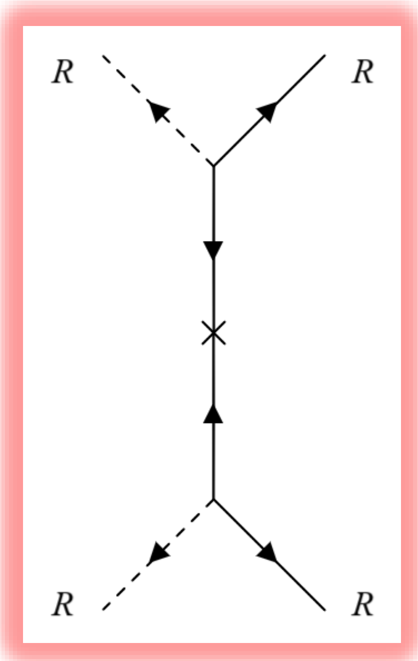
$SU(5)^{q(X)}$	$3_c \times 2_L \times 1_Y$	$q(R)$	$\mathbb{Z}_2$
10^1	$Q(3\ 2\ 1/6)$ $D^c(\bar{3}\ 1\ 1/3)$ $N^c(1\ 1\ 0)$	0	−1
$\bar{5}^{-3}$	$U^c(\bar{3}\ 1\ -2/3)$ $L(1\ 2\ -1/2)$	0	−1
1^5	$E^c(1\ 1\ 1)$	0	−1
10^1_H	$Q_H(3\ 2\ 1/6)$ $D^c_H(\bar{3}\ 1\ 1/3)$ $N^c_H(1\ 1\ 0)$	0	+1
$\overline{10}^{-1}_H$	$\overline{Q_H}(\bar{3}\ 2\ -1/6)$ $\overline{D^c_H}(3\ 1\ -1/3)$ $\overline{N^c_H}(1\ 1\ 0)$	0	+1
5^{-2}_h	$D_h(3\ 1\ -1/3)$ $H_d(1\ 2\ -1/2)$	1	+1
$\bar{5}^2_h$	$\overline{D_h}(\bar{3}\ 1\ 1/3)$ $H_u(1\ 2\ 1/2)$	1	+1
S	$S(1\ 1\ 0)$	1	+1

CHIRALITY TYPES

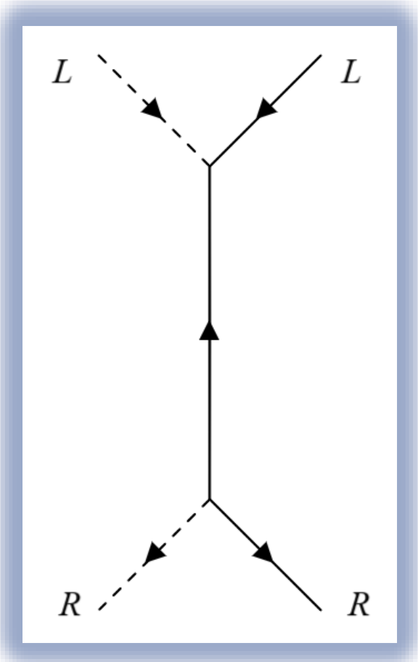
LLLL



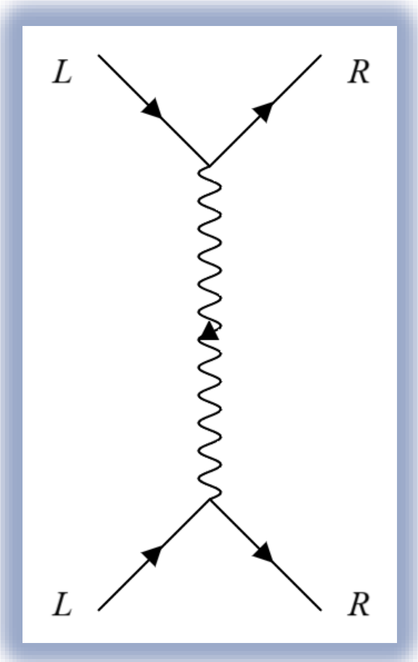
RRRR



LLRR



LRLR



Solid line: fermion, Dashed line: boson, Wavy line: gauge boson
L: left chiral, R: right chiral

PROTON DECAY IN FLIPPED SU(5):

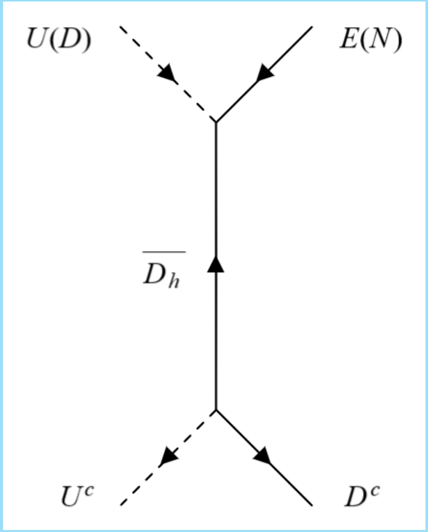
- I- Dimension four operators (rapid proton decay) forbidden by $\mathbb{Z}_2$ matter parity and $U(1)_R$ symmetry
- II-Dimension five operators (rapid proton decay) forbidden by $U(1)_R$ symmetry, no GUT scale mass terms for Higgs 5-plet $5_h\bar{5}_h$ and Higgs 10-plet $10_H\overline{10}_H$
- III-Dimension six operators (observable proton decay) of chirality type LLRR is mediated via color triplets of 5-plets and chirality type LRLR is mediated via gauge bosons
  - Proton decay interaction terms from W:

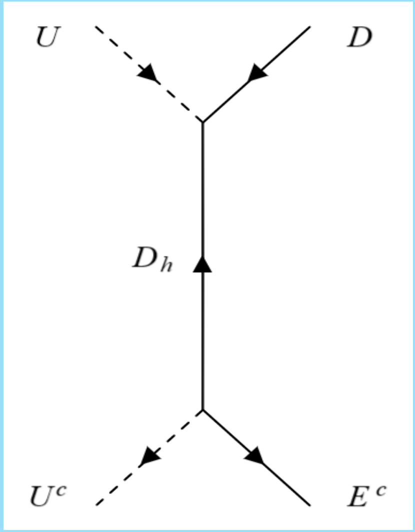
$$W \supset L\left(U_L\, y_D^{(u,\nu)}\right) Q\, \overline{D_h} + U^c\left(y_D^{(u,\nu)} V P^*\right) D^c \overline{D_h}$$
$$-\frac{1}{2} Q\left(V^* P\, y_D^{(d)}\, V^\dagger\right) Q\, D_h + U^c\left(U_L^\dagger\, y_D^{(e)}\right) E^c D_h$$

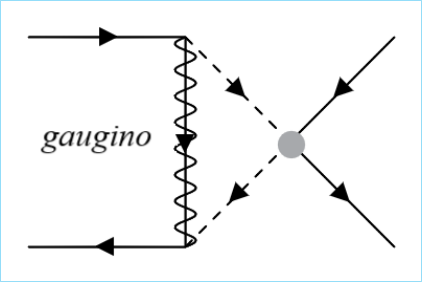
  - Proton decay interaction terms from K:

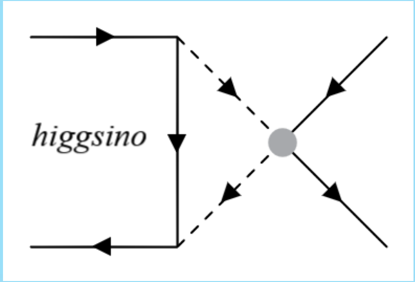
$$K \supset \sqrt{2}\, g_5\left(-(U^c)^\dagger \mathcal{X}(U_L^T L) + (Q)^\dagger \mathcal{X}(V P^* D^c) + \text{h.c.}\right)$$

DIMENSION SIX:
I-TWO FERMIONS TWO SCALARS OPERATOR









- Non-chirality flipping operator LLRR with two fermions and two scalars is dimension six operator!

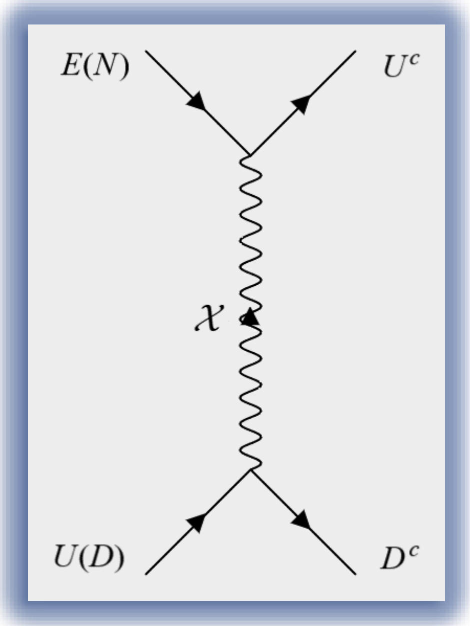
$$\mathcal{L} \supset \frac{1}{m_P^2}\int d^4\theta\, \Phi\Phi^\dagger\Phi\Phi^\dagger \supset \frac{1}{m_P^2}\overline{\psi}\,\partial\!\!\!/\,\psi\,\phi^*\phi$$

where

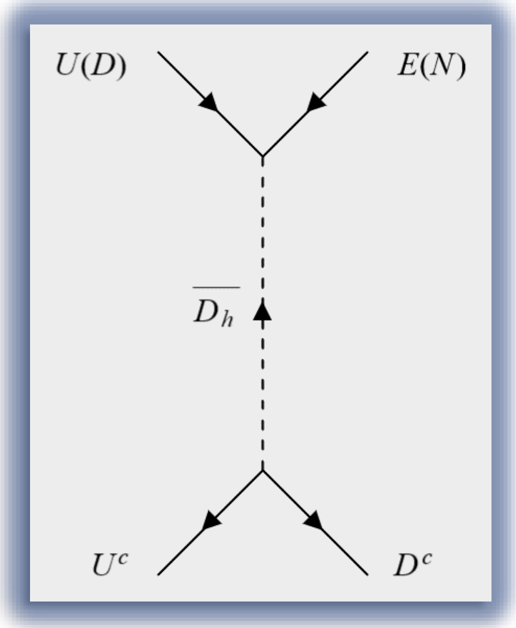
$$\Phi \supset \phi(x) + \sqrt{2}\theta\psi(x) - i\frac{1}{\sqrt{2}}\theta^2\partial^\mu\psi(x)\sigma_\mu\bar{\theta}.$$

- Needs a box diagram to become effective four fermi operator.
- This contribution is suppressed by loop factor

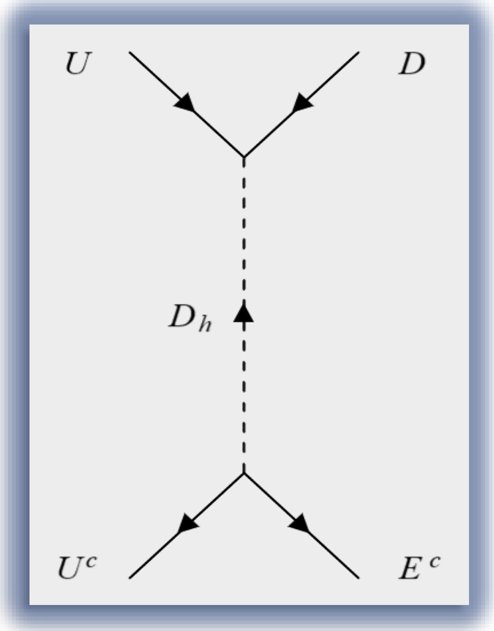
DIMENSION SIX:
II- FOUR FERMIONS PROTON DECAY OPERATORS



(a)



(b)



(c)

Dimension six proton decay mediated via gauge bosons (a) and color triplets of 5-plet (b) and (c).

DIMENSION SIX: PROTON DECAY OPERATORS

- Effective dimension six proton decay operators:

$$\mathcal{L}_6^{\rm eff} = C_{6(1)}^{ijkl}\,(U^c)_i^\dagger\,(D^c)_j^\dagger\,Q_k\,L_l + C_{6(2)}^{ijkl}\,Q_i\,Q_j\,(U^c)_k^\dagger\,(E^c)_l^\dagger,$$
$$\supset (U^c)_i^\dagger\,(D^c)_j^\dagger\,C_{6(1)}^{ijkl}(U_k E_l + (V D)_k (U_{PMNS} N)_l)$$
$$+(U_i\,(V\,D)_j + (V\,D)_i\,U_j)\,C_{6(2)}^{ijkl}\,(U^c)_k^\dagger\,(E^c)_l^\dagger,$$

- Wilson coefficients:

$$C_{6(1)}^{ijkl} = e^{i\varphi_j}\left(\frac{(U_L)_{li}V_{kj}^*}{M^2} + \frac{(V^\dagger\,y_D^{(u,\nu)})_{ji}(U_L\,y_D^{(u,\nu)})_{lk}}{M_{\bar\lambda}^2}\right),$$
$$C_{6(2)}^{ijkl} = -\left(\frac{(V^*\,P\,y_D^{(d)}\,V^\dagger)_{ij}(U_L^T\,y_D^{(e)})_{kl}}{2M_\lambda^2}\right).$$

where,

$$M_\lambda = \lambda\ M \qquad\qquad M_{\bar\lambda} = \bar\lambda\ M$$

DECAY RATES:
1-CHARGED LEPTON (ELECTRON, MUON) CHANNELS

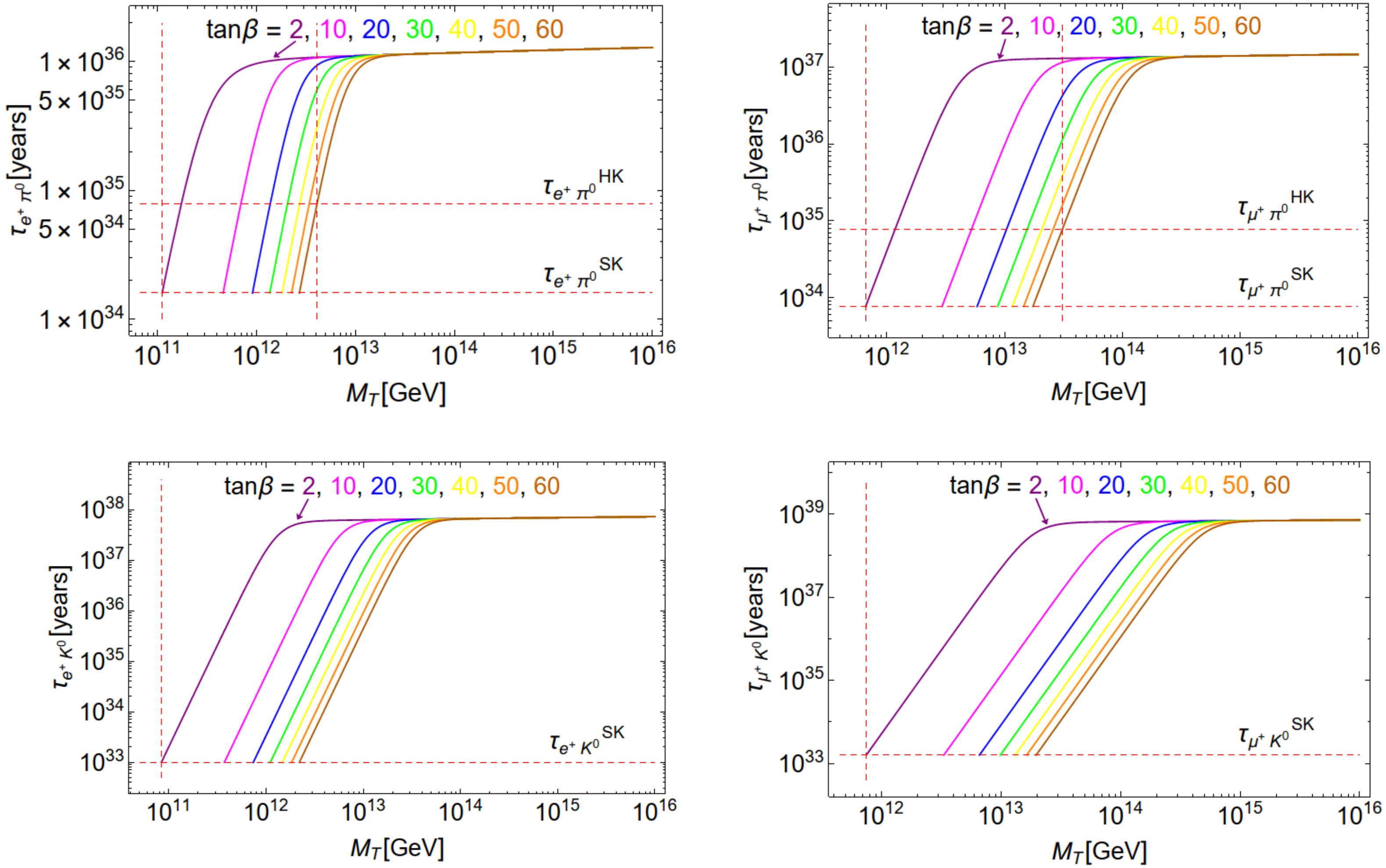
$$\Gamma_{p\to\pi^0 l_i^+} = k_\pi |C_{\pi^0 l_i^+}|^2 \left(A_{S_1}^2 \left| \frac{1}{M^2} + \left(\frac{m_u}{v_u}\right)^2 \frac{1}{M_\lambda^2} \right|^2 + A_{S_2}^2 \left| \frac{m_d}{v_d}\frac{m_{l_i}}{v_d}\frac{1}{M_\lambda^2} \right|^2 \right),$$

$$\Gamma_{p\to K^0 l_i^+} = k_K |C_{K^0 l_i^+}|^2 \left(A_{S_1}^2 \left| \frac{1}{M^2} + \left(\frac{m_u}{v_u}\right)^2 \frac{1}{M_\lambda^2} \right|^2 + A_{S_2}^2 \left| \frac{m_s}{v_d}\frac{m_{l_i}}{v_d}\frac{1}{M_\lambda^2} \right|^2 \right),$$

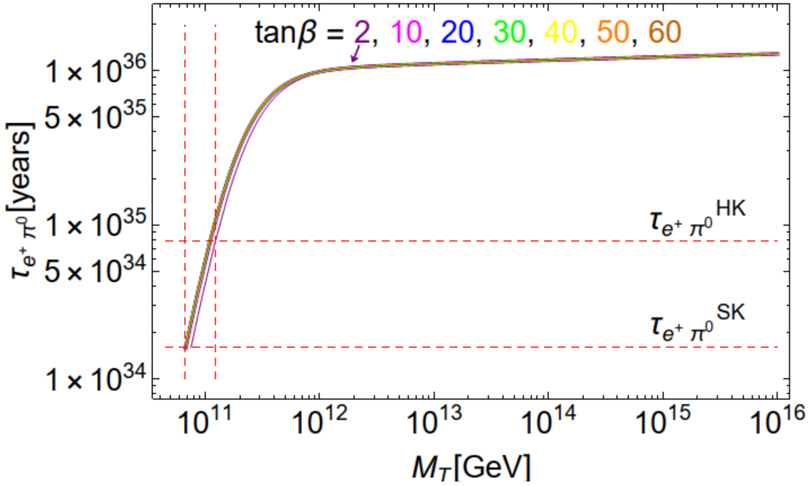
$$k_\pi = \frac{m_p A_L^2}{32\pi}\left(1 - \frac{m_\pi^2}{m_p^2}\right)^2, \quad k_K = \frac{m_p A_L^2}{32\pi}\left(1 - \frac{m_K^2}{m_p^2}\right)^2,$$

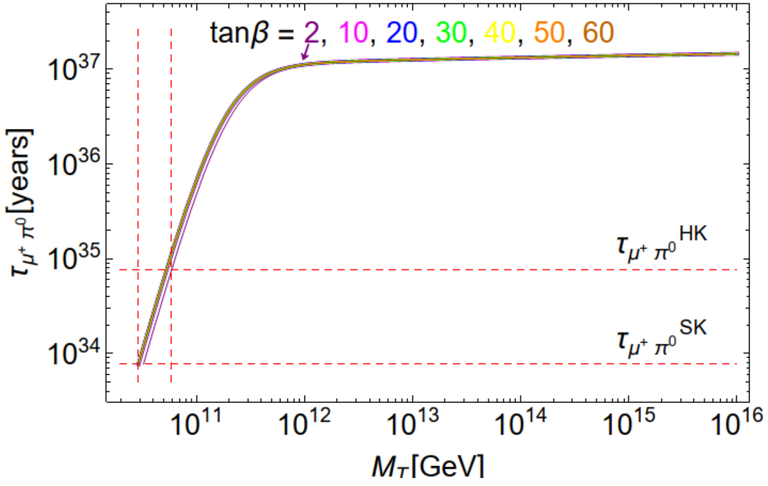
$$C_{\pi^0 l_i} = T_{\pi^0 l_i}(U_L)_{i1} V_{ud}^*, \qquad C_{K^0 l_i} = T_{K^0 l_i}(U_L)_{i1} V_{us}^*.$$

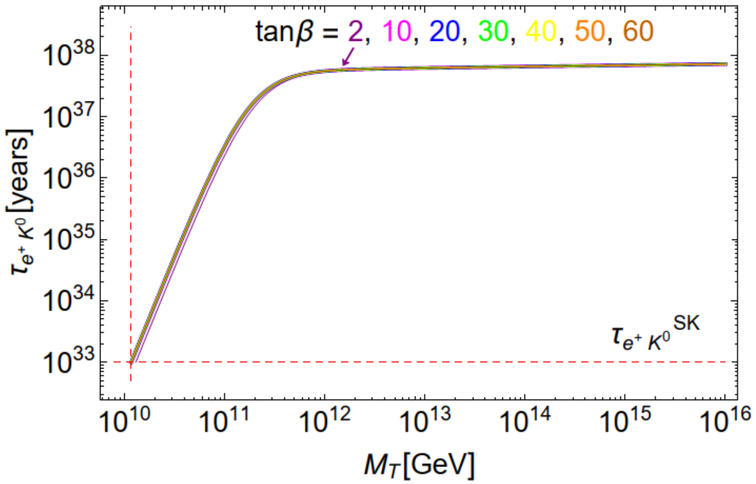
CASE I: $M_T = M_\lambda = M_{\bar{\lambda}}$

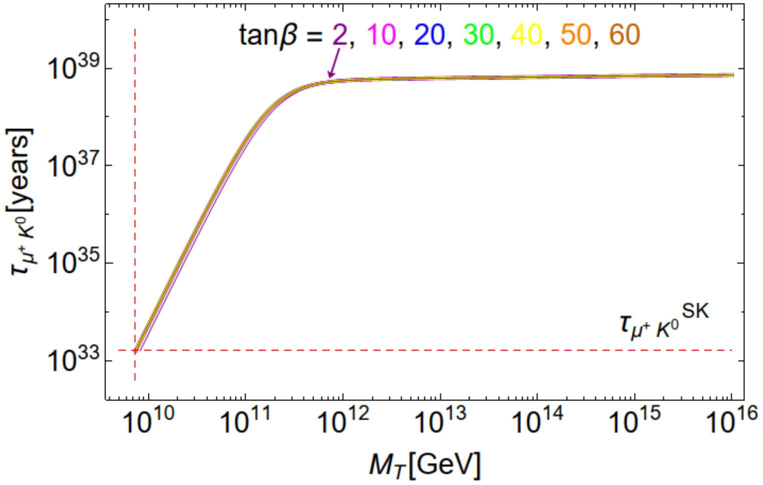


CASE II: $M_T = M_{\bar{\lambda}} << M_\lambda$









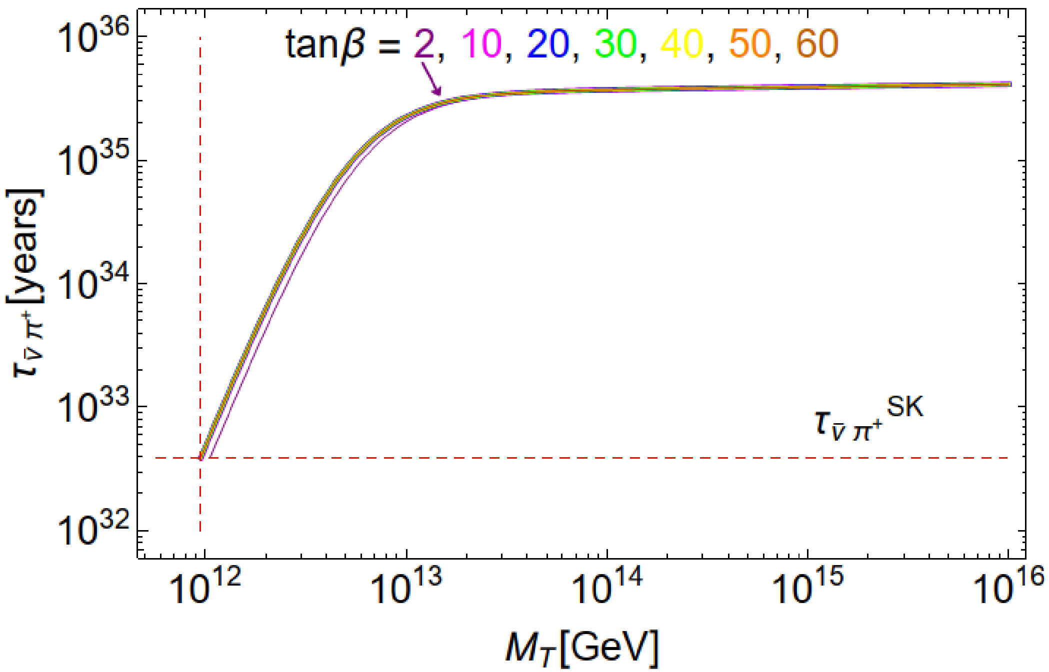
DECAY RATES:
II-NEUTRAL LEPTON (NEUTRINO) CHANNELS

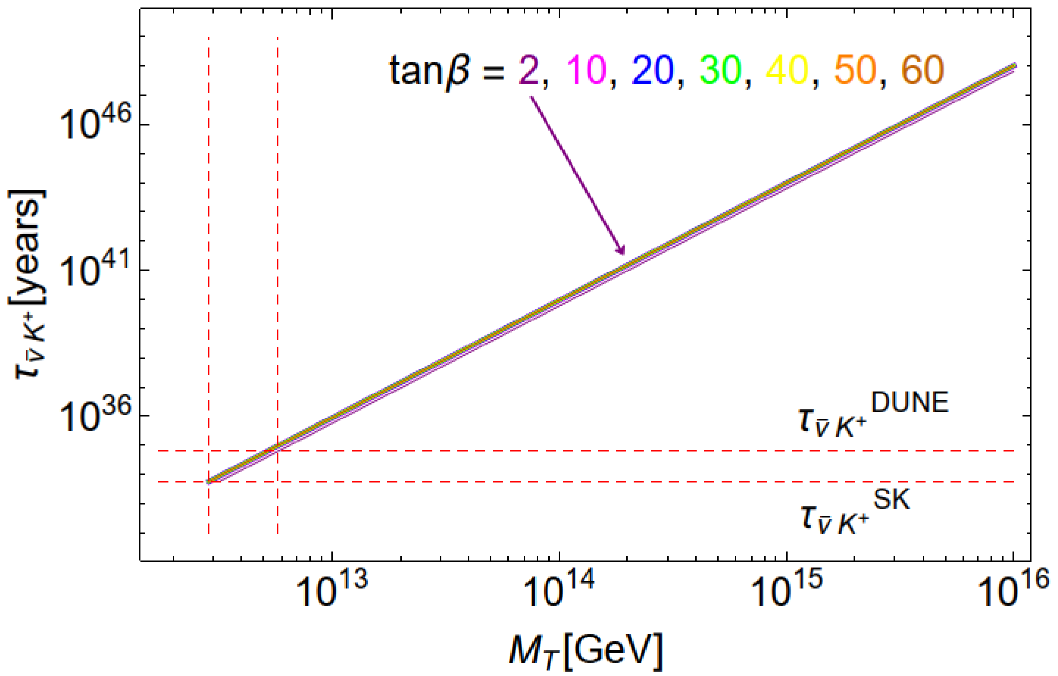
$$\Gamma_{p\to\pi^+\bar{\nu}_i} = k_\pi |T_{\pi^+\bar{\nu}}|^2 A_{S_1}^2 \left| \frac{(U_N^*)_{i1}}{M^2} + V_{ud} \frac{m_u}{v_u} \sum_j \frac{(m^{(u)})_j}{v_u} \frac{(U_N^*)_{ij} (V)_{j1}}{M_{\bar{\lambda}}^2} \right|^2 ,$$

$$\Gamma_{p\to K^+\bar{\nu}_i} = k_K A_{S_1}^2 \left| e^{i\varphi_1} T'_{K^+\bar{\nu}} (V^*)_{ud} \frac{m_u}{v_u} \sum_j \frac{(m^{(u)})_j}{v_u} \frac{(U_N^*)_{ij} (V)_{j2}}{M_{\bar{\lambda}}^2} \right.$$

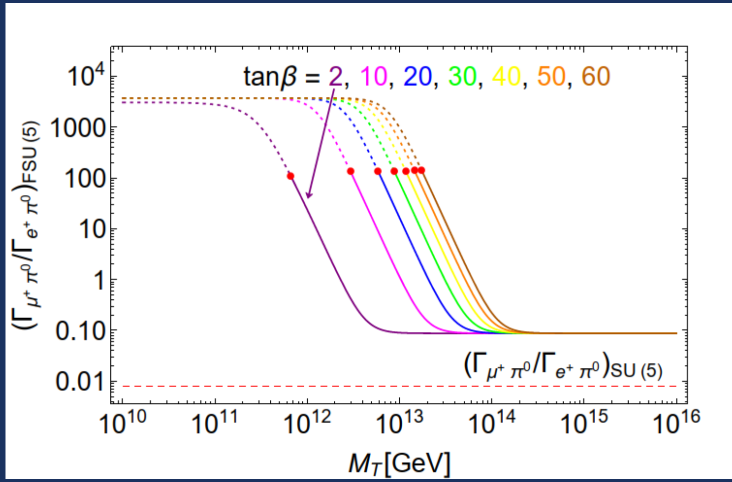
$$\left. + e^{i\varphi_2} T''_{K^+\bar{\nu}} (V^*)_{us} \frac{m_u}{v_u} \sum_j \frac{(m^{(u)})_j}{v_u} \frac{(U_N^*)_{ij} (V)_{j1}}{M_{\bar{\lambda}}^2} \right|^2 .$$

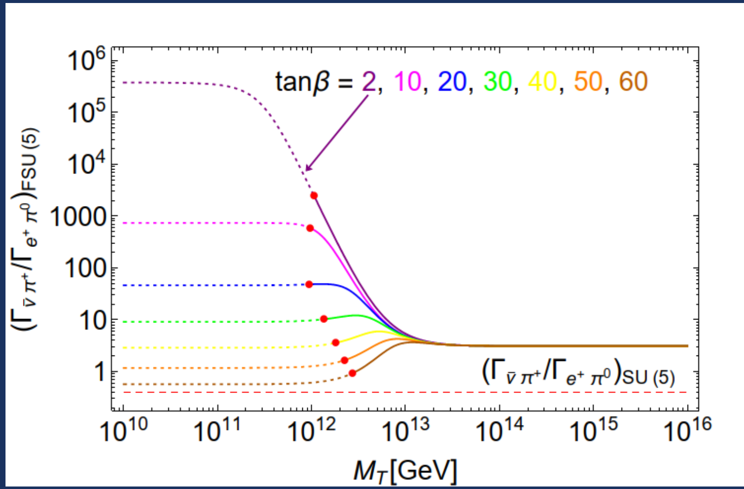
$M_T = M_{\bar{\lambda}}$, M_λ not involved!

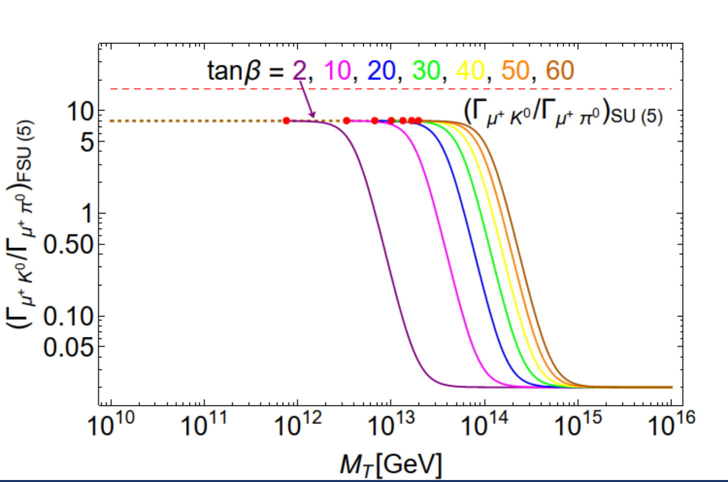


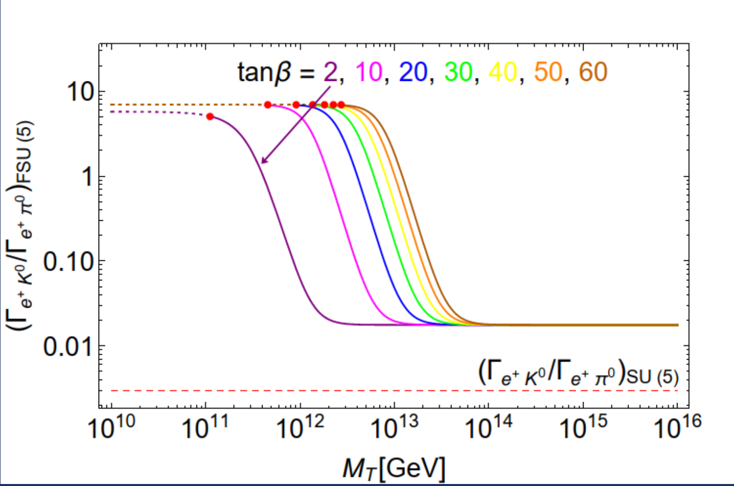


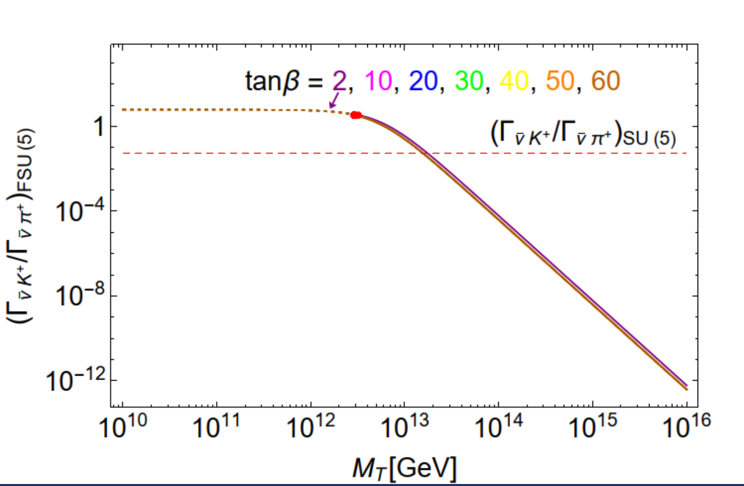
FLIPPED SU(5) vs. SU(5)

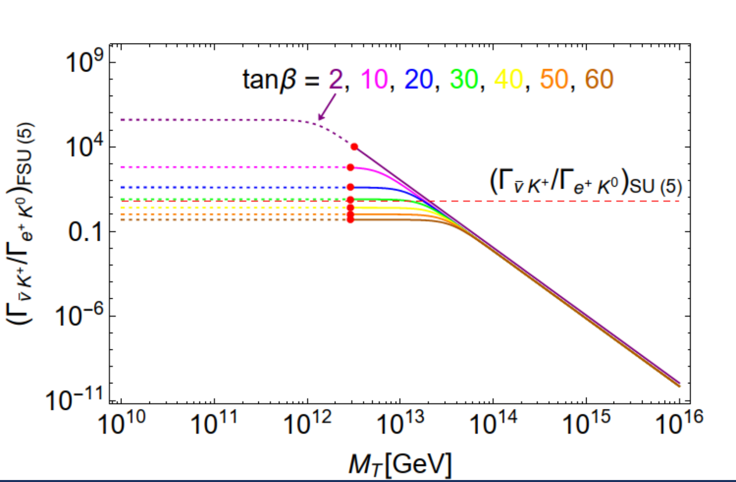




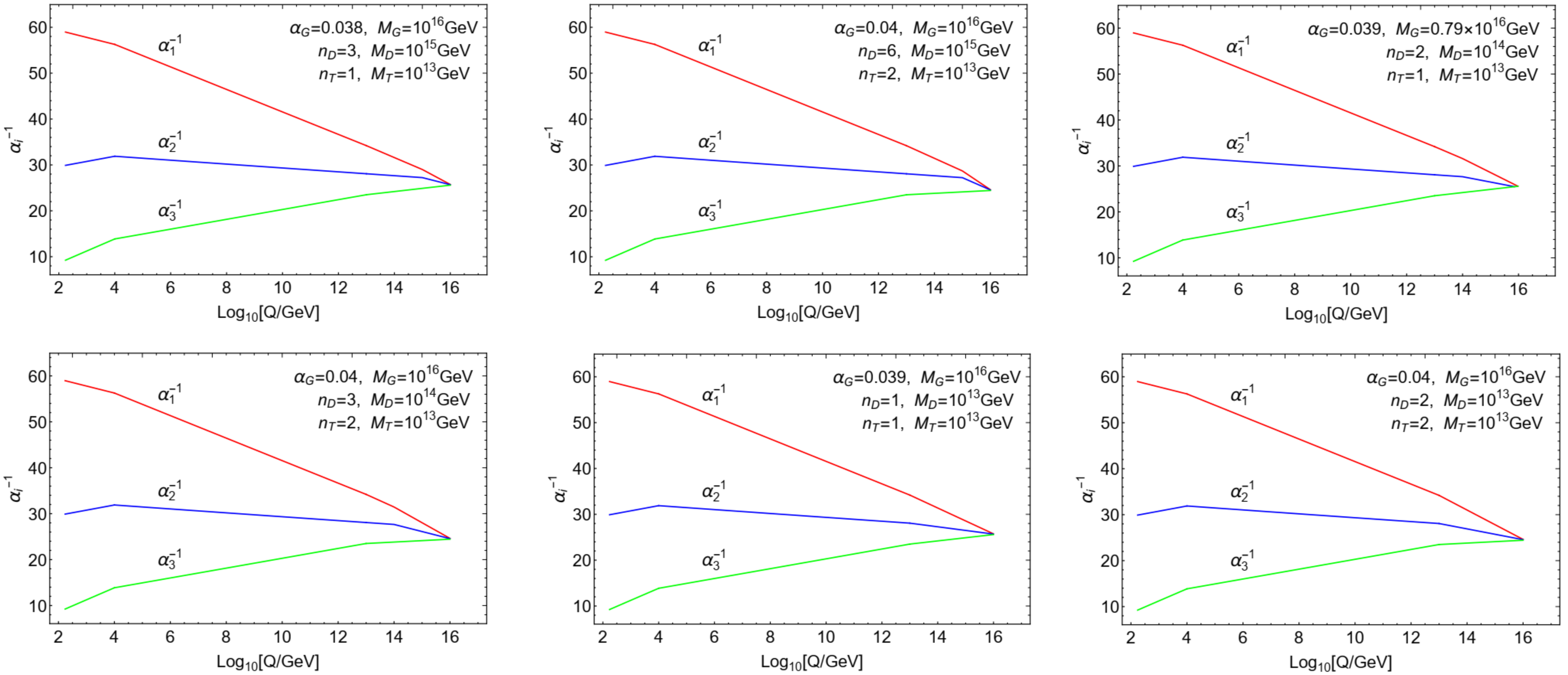








GAUGE COUPLING UNIFICATION



SUMMARY

- R-symmetric flipped SU(5) model.
- R symmetry forbids rapid proton decay via dimension four or five operators.
- Color triplets of intermediate mass from Higgs 5-plets mediate proton decay with lifetime that lie in the observable range of future experiments.
- Anti-neutrino and Kaon channel plays a pivotal role in distinguishing our model from SU(5) and other flipped SU(5) models.
- Flipped SU(5) model can be embedded into SO(10) group.

Thank you!

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