Proton Lifetime in Minimal SUSY SU(5)

Cem Salih Ün

Department of Physics, Bursa Uludağ Univeristy

in collaboration with
K. S. Babu and Ilia Gogoladze

Outline

The Standard Model

- The SM is a gauge theory of fields of spin 0, 1/2 and 1 based on $SU(3)_c \times SU(2)_L \times U(1)_Y$

  $SU(3)_c \rightarrow$ QCD, confinement

  $SU(2)_L \times U(1)_Y \rightarrow$ electroweak interactions, chiral, spontaneous symmetry breaking

  $$SU(2)_L \times U(1)_Y \rightarrow U(1)_{\mathrm{em}}$$

- The SM is one of the most successful theories in physics. It has been tested rigorously.

  $W^{\pm}, Z$ bosons

  Rare B-meson decays: $B_s \rightarrow \mu^+\mu^-$, $b \rightarrow s\gamma$

  The Higgs Boson

SM is not a fundamental theory!

- Gauge Hierarchy problem: $\delta m_h^2 \propto \Lambda^2$
- The gauge symmetry
- The Higgs vacuum stability: $\lambda < 0$ for $\Lambda \gtrsim 10^{10}$ GeV

  Stability Condition: $m_h > (129.6 \pm 1.5)$ GeV
- Neutrino masses and mixings
- Dark matter

- **Resolution to the gauge hierarchy problem.**
- R-Parity: $R = (-1)^{3B+L+2S} \Rightarrow$ Stable LSP
- Radiative Electroweak Symmetry Breaking

$$V_H = (|\mu|^2 + m_{H_u}^2)|H_u^0|^2 + (|\mu|^2 + m_{H_d}^2)|H_u^d|^2 - (bH_u^0 H_d^0 + \text{c.c.})$$

$$+\frac{1}{8}(g + g')(|H_u^0|^2 - |H_d^2|)^2$$

$$2b < (|\mu|^2 + m_{H_u}^2) + (|\mu|^2 + m_{H_d}^2) \qquad m_{H_u} \neq m_{H_d}$$

$$b^2 > (|\mu|^2 + m_{H_u}^2)(|\mu|^2 + m_{H_d}^2) \qquad m_{H_u} < 0,\ m_{H_u} \ll m_{H_d}$$

- **Unification of gauge couplings**

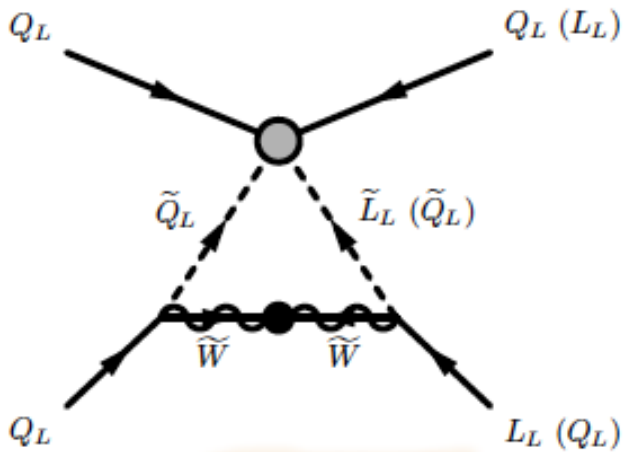
SUSY GUT - $SU(5)$

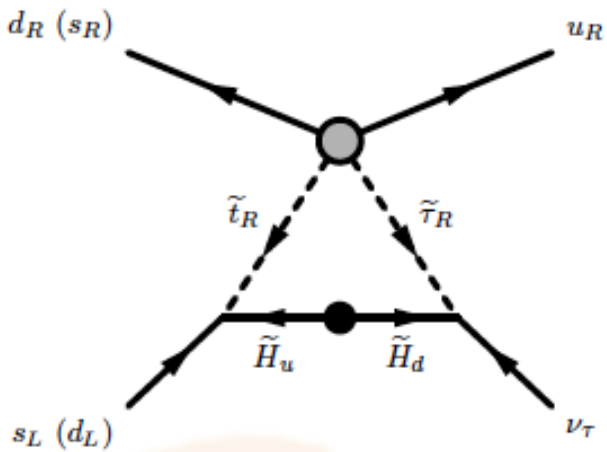
$$\bar{5} = \begin{pmatrix} d_1^c \\ d_2^c \\ d_3^c \\ e \\ -\nu \end{pmatrix}, \quad 10 = \begin{pmatrix} 0 & u_3^c & -u_2^c & u_1 & d_1 \\ -u_3^c & 0 & u_1^c & u_2 & d_2 \\ u_2^c & -u_1^c & 0 & u_3 & d_3 \\ -u_1 & -u_2 & -u_3 & 0 & e^c \\ -d_1 & -d_2 & -d_3 & -e_c & 0 \end{pmatrix}$$

MSSM Higgs doublets: $H_u, H_d \in H, \overline{H} \Rightarrow \mathbf{y_{d_i}} = \mathbf{y_{l_i}}$

$$H = \left(H_{1C},\, H_{2C}\, H_{3C},\, H_u^+,\, H_u^0\right)^T, \quad \overline{H} = \left(\overline{H}_{1C},\, H_{2C},\, \overline{H}_{3C},\, H_d^-,\, -H_d^0\right)^T .$$

Wrong Mass Relations: $\mathbf{m_\mu/m_s = 1}$



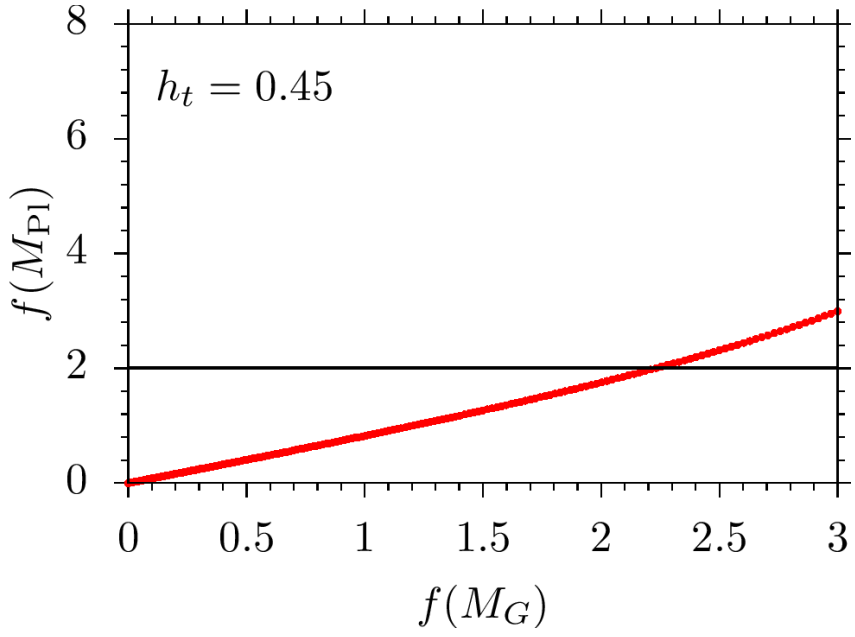


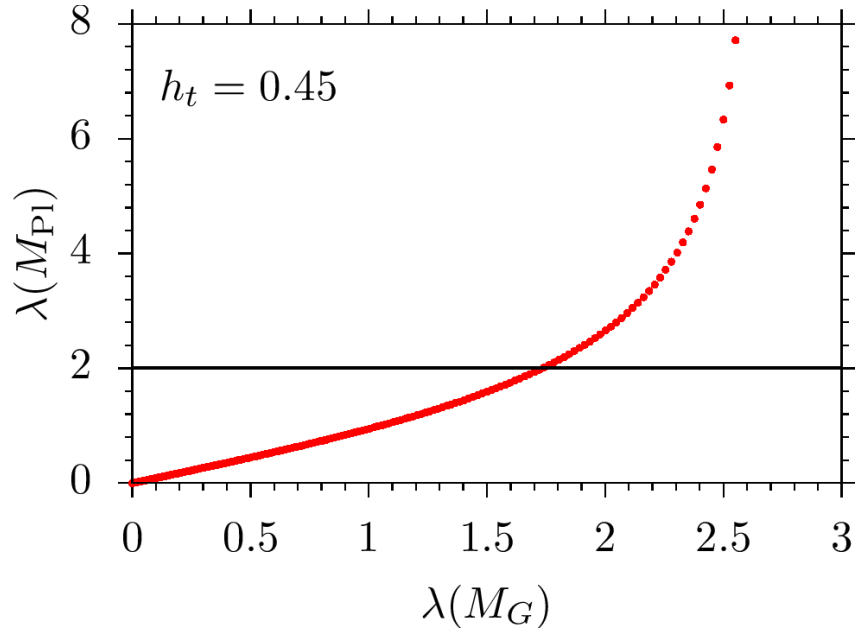
Renormalizable SU(5):

$$W_5 = \frac{m_\Sigma}{2}\mathrm{Tr}(\Sigma^2) + \frac{1}{3} f\,\mathrm{Tr}(\Sigma^3) + m_H \overline{H} H + \lambda\, \overline{H}\Sigma H \ , \text{ with}$$

$$\langle \Sigma \rangle = \mathrm{diag.}(2,\, 2,\, 2,\, -3,\, -3) \times \sigma \ ,$$

$$M^0_{H_C} = m_H + 2\lambda\sigma \ , \ \mu = m_H - 3\lambda\sigma \ .$$





$$f(M_G) \leq 2.24 \text{ and } \lambda(M_G) \leq 1.75$$

Planck Suppressed Operators

Gravitational Smearing:

$$\delta\mathcal{L} = \frac{c}{2M_{\rm Pl}}\mathrm{tr}(GG\Sigma) \ ,$$

$$(-2\alpha_3^{-1}+3\alpha_2^{-1}-\alpha_1^{-1})(m_Z) = \frac{1}{2\pi}\left\{\frac{12}{5}\,\ln\frac{M^0_{H_C}}{m_Z} - 2\ln\frac{m_{SUSY}}{m_Z}\right\} - \frac{6\sigma\, c}{M_{\rm Pl}}\alpha_5^{-1} \ .$$

$$M_{H_C} = M^0_{H_C} \times \exp\left(\frac{-5\pi\sigma c}{\alpha_5 M_{\rm Pl}}\right)$$

Live Long "c", the negative!

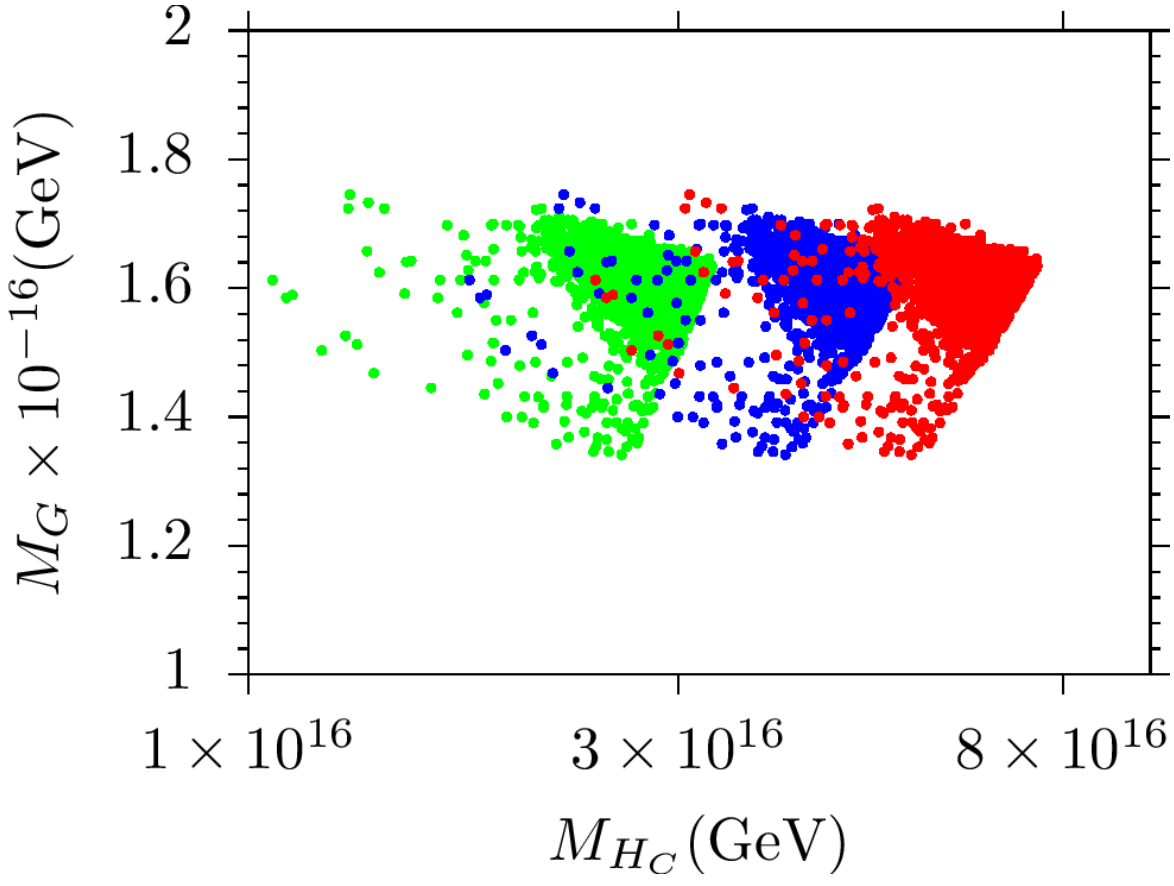
SU(5) Breaking

Corrections to the $SU(5)$ breaking:

$$W' = \frac{\kappa_1}{4}\mathrm{tr}(\Sigma^4) + \frac{\kappa_2}{4}\left(\mathrm{tr}(\Sigma^2)\right)^2 \ , \quad [\kappa_i] = M^{-1} \ .$$

$$\begin{aligned} M_{\Sigma_8} &= \frac{5}{2} f\sigma + \frac{5}{2}\kappa_1\sigma^2 \ , \\ M_{\Sigma_3} &= \frac{5}{2} f\sigma - 10\kappa_1\sigma^2 \ . \end{aligned}$$

$$(-2\alpha_3^{-1} + 3\alpha_2^{-1} - \alpha_1^{-1})(m_Z) = \frac{1}{2\pi}\left\{\frac{12}{5}\ln\frac{M_{H_C}}{m_Z} + 6\ln\frac{M_{\Sigma_8}}{M_{\Sigma_3}} - 2\ln\frac{m_{SUSY}}{m_Z}\right\}$$



$M_{H_C} \simeq 3 \times 10^{16}$ – No Correction

$M_{H_C} \simeq 5.35 \times 10^{16}$ – Gravitational Smearing

$M_{H_C} \simeq 7.2 \times 10^{16}$ – SU(5) Breaking

Fundamental Parameters

$0 \leq$	$m_{0_{1,2}}, m_{0_3}$	≤ 30 TeV	SSB masses for matter scalars
$0 \leq$	$M_{1/2}$	≤ 2 TeV	SSB masses for gauginos
$1.2 \leq$	$\tan\beta$	≤ 20	$\tan\beta \equiv v_u/v_d$
$-3 \leq$	A_0/m_{0_3}	≤ 3	SSB trilinear scalar coupling
-10 TeV $\leq$	A_0	≤ 10 TeV	
$0 \leq$	μ, m_A	≤ 30 TeV	

Experimental Constraints

$$123 \leq \quad m_h \quad \leq 127 \text{ GeV}$$
$$m_{\tilde{g}} \quad \geq 2100 \text{ GeV}$$

$$0.8 \times 10^{-9} \leq \text{BR}(B_s \to \mu^+\mu^-) \leq 6.2 \times 10^{-9}$$

$$2.9 \times 10^{-4} \leq \text{BR}(b \to s\gamma) \leq 6.2 \times 10^{-9}$$

$$0.114 \leq \Omega h^2(\text{Planck}) \leq 0.126$$

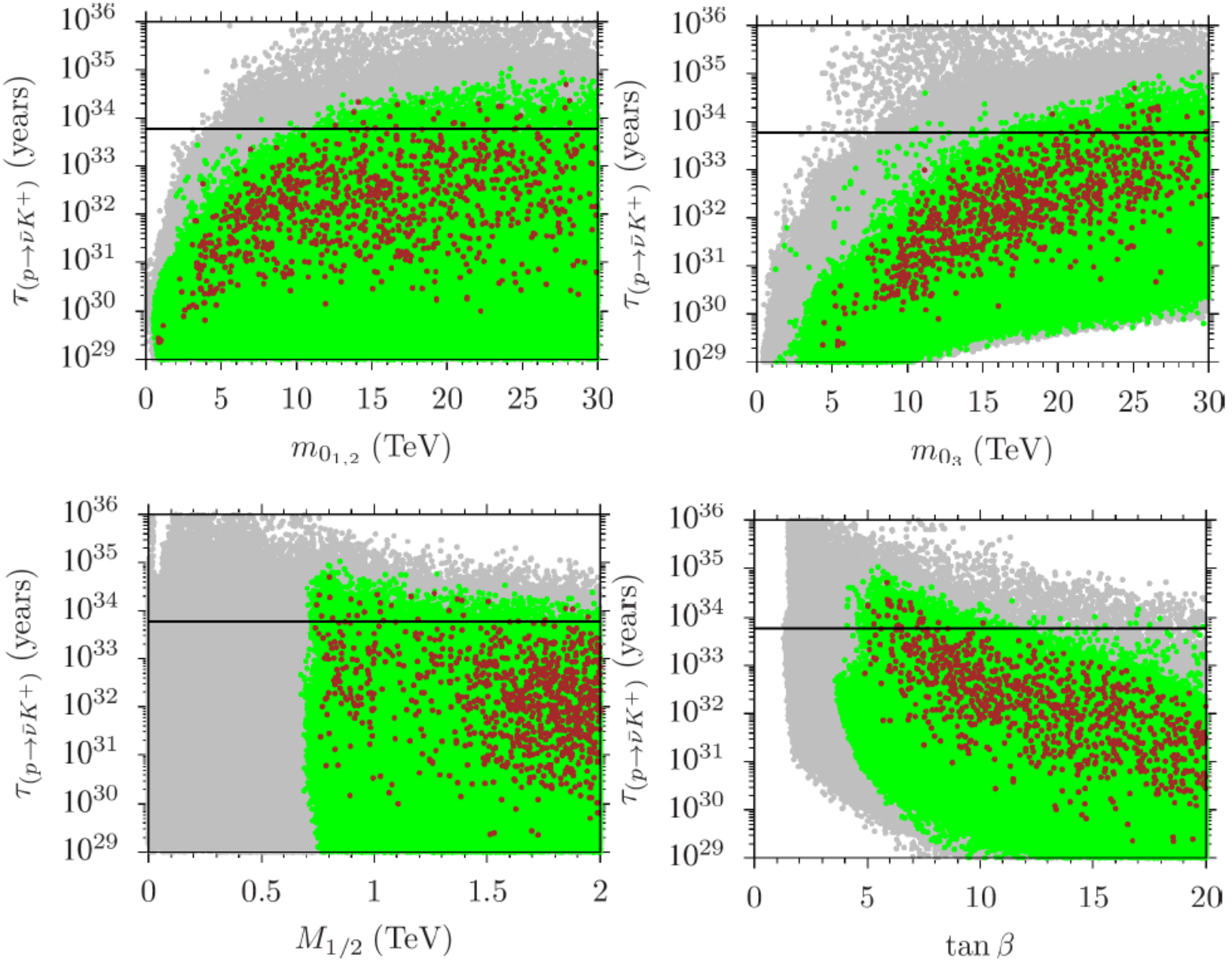
$$m_t = 173.3 \text{ GeV} \qquad M_{H_C} = 7 \times 10^{16} \text{ GeV}$$

$$\tau(p \to \bar{\nu} K^+) \geq 5.9 \times 10^{33} \text{ years}$$

Color Coding:

- LHC allowed
- LHC + PD
- LHC + PD + DM

Proton Decay in SU(5)



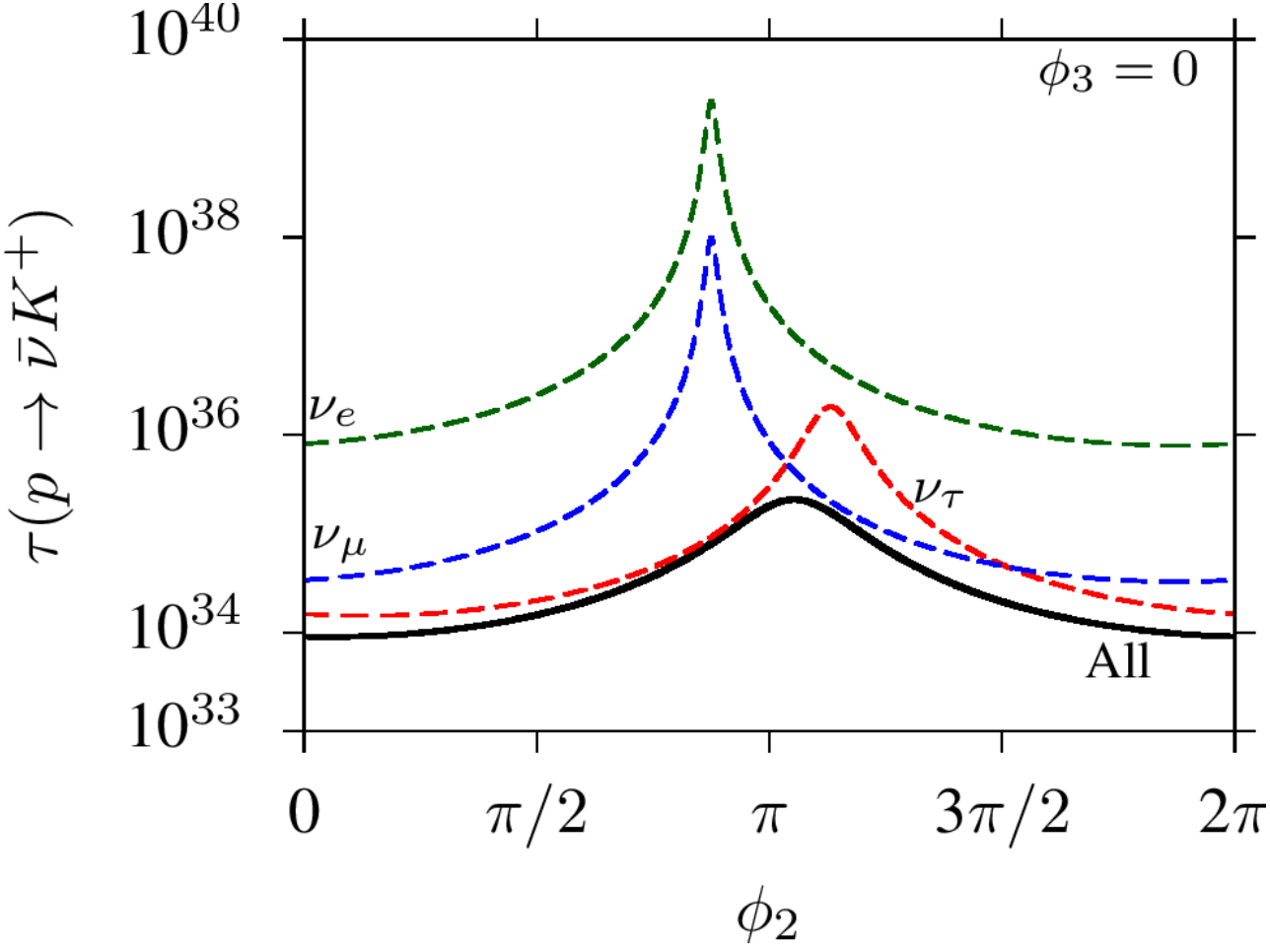


Figure: Lifetime of the proton in correlation with the phase angle ϕ_2 with ϕ_3 set to zero. Green, blue and red dashed curves represent the proton decay into ν_e, ν_μ and ν_τ along with K^+, respectively. The solid dashed curve shows the total lifetime of the proton.

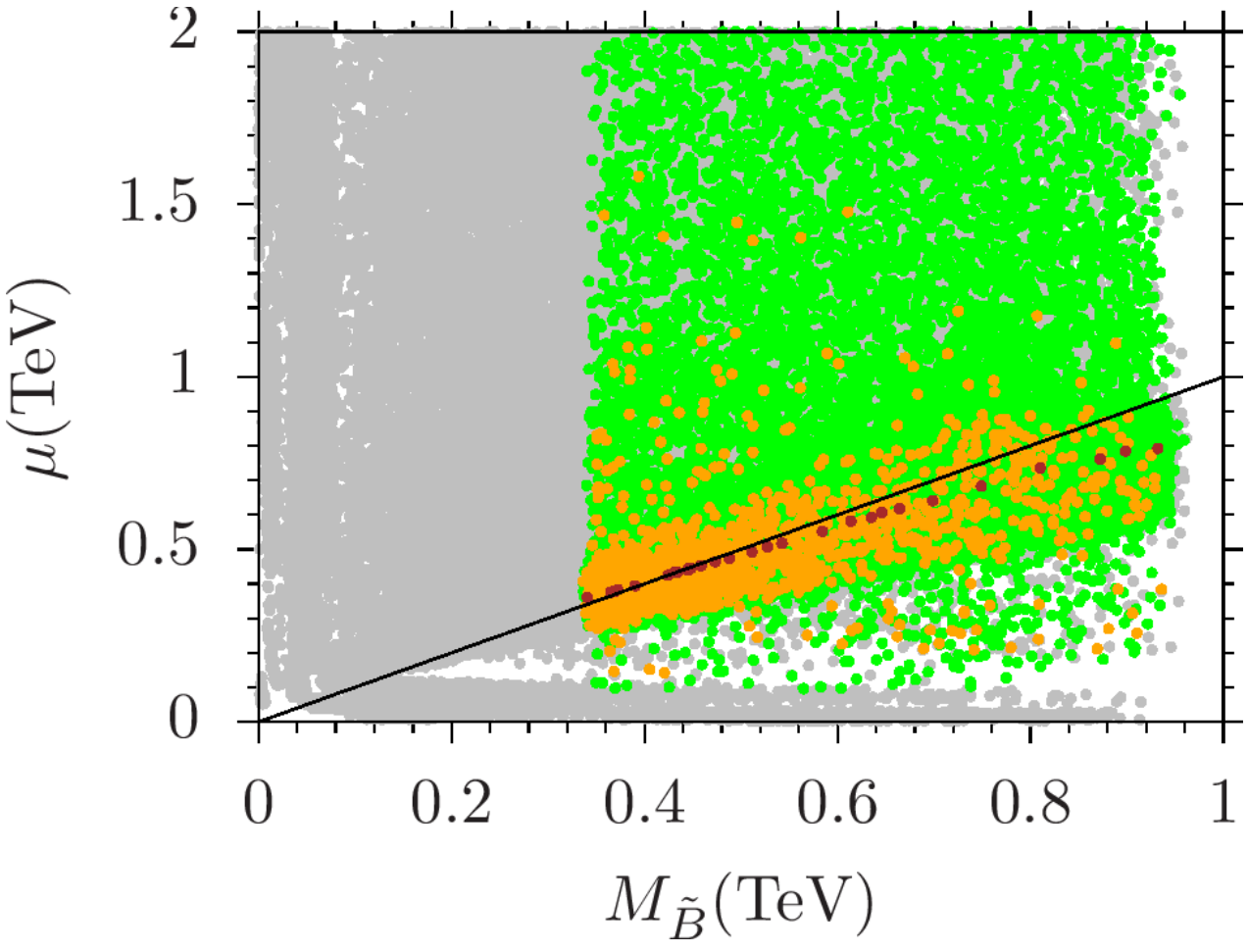
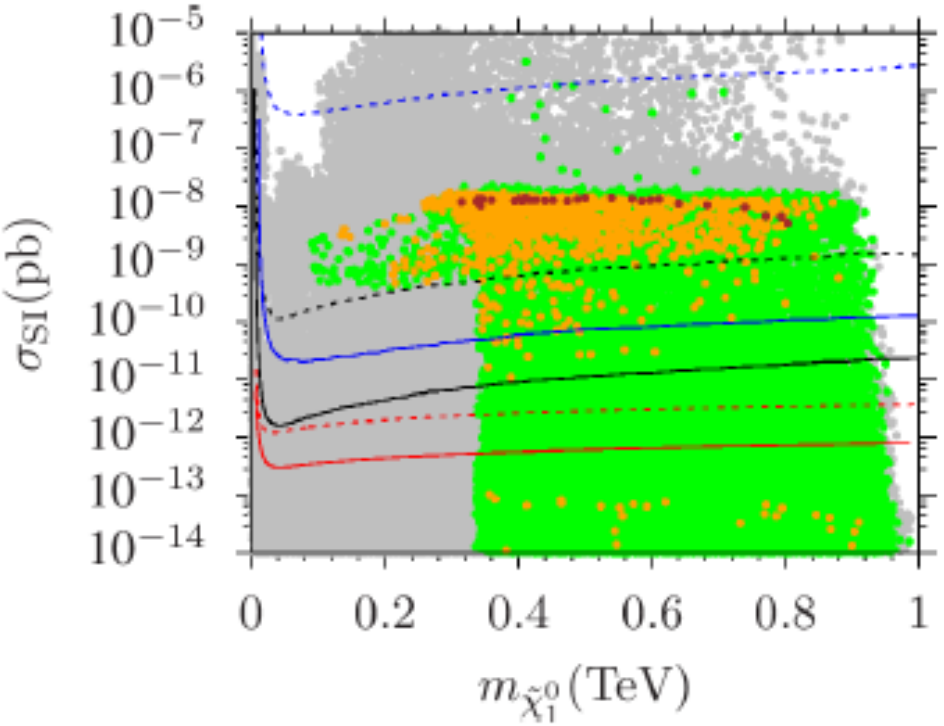
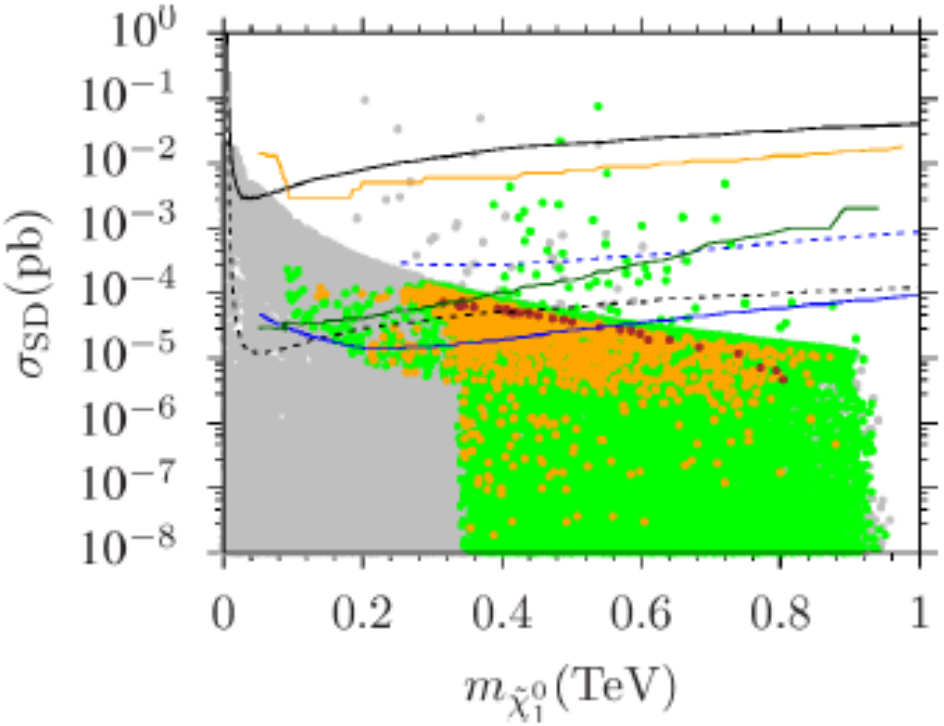


Figure: Plot for the neutralino species in the $\mu - M_1$ plane.

Direct Detection of DM





Conclusion

- Planck Suppressed operators enhance proton lifetime.
- Still strong impact from the proton decay
- $\tan\beta \lesssim 12$
- Heavy supersymmetric mass spectrum:

$$m_{0_{1,2}} \gtrsim 10 \text{ TeV and } m_{0_3} \gtrsim 15 \text{ TeV}$$

- Bino-Higgsino mixture in Dark Matter composition
- Large scattering cross-sections in direct detection experiments of Dark Matter