

Compressed and Split Spectra in Minimal SUSY SO(10)

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Motivation

- Motivations for SUSY and GUTs

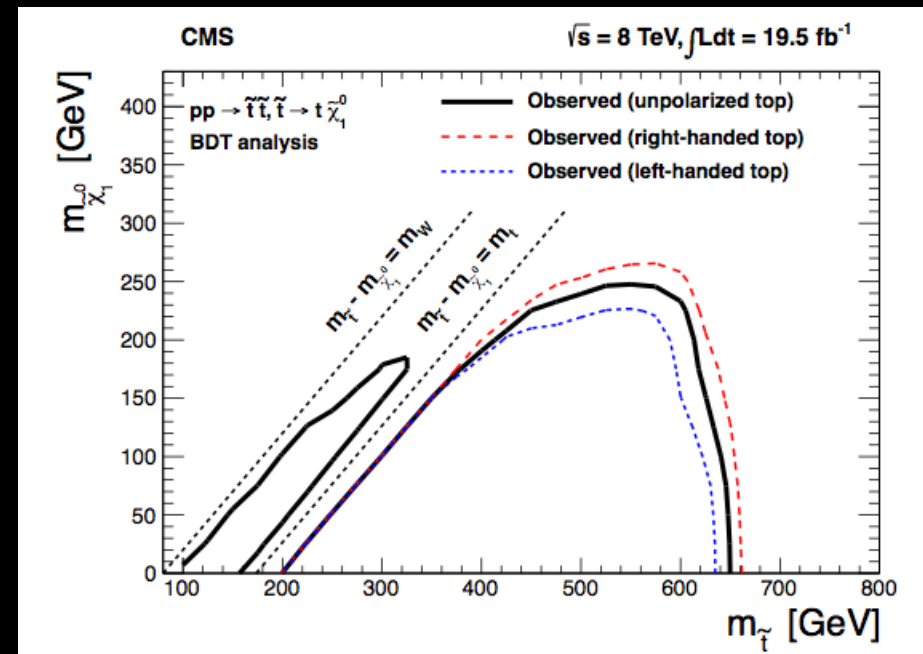
- Lack of SUSY signals

- Strong limits on masses

$$m_{\tilde{q}} > 2 \text{ TeV}, m_{\tilde{g}} > 1 \text{ TeV},$$

$$m_{\tilde{l}} > 300 \text{ GeV}, m_{\tilde{t}} > 600 \text{ GeV}$$

- SUSY might be hiding



Minimal SUSY SO(10)

- Matter sector, all left-handed matter particles

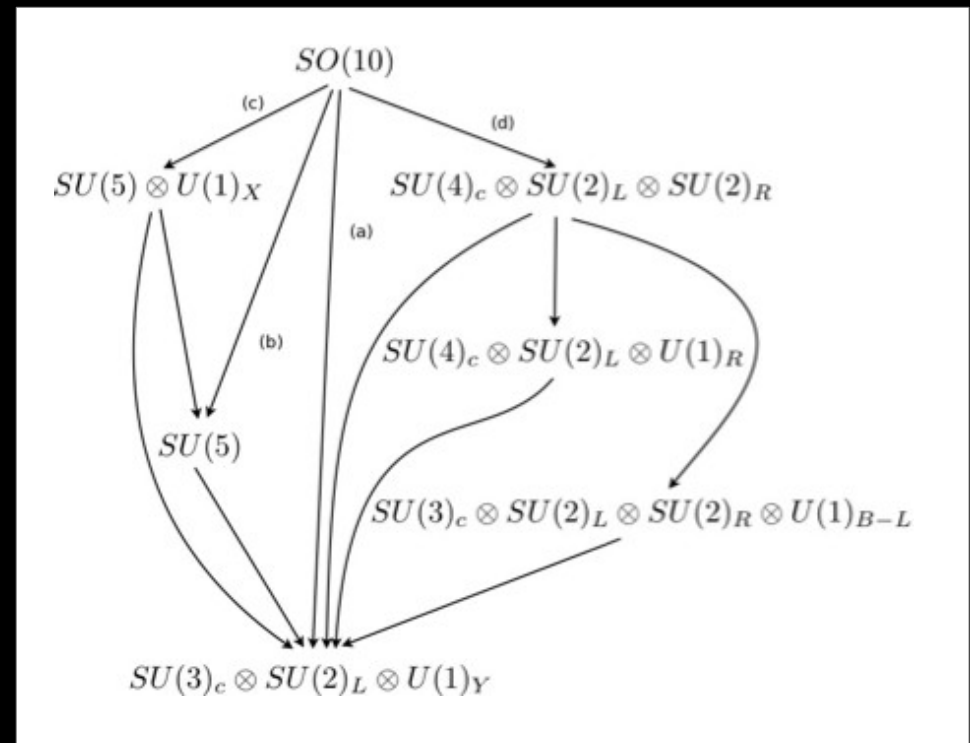
$$\mathbf{16}_F = \{u_1^c, d_1^c, d_1, u_1, \nu^c, e^c, d_2, u_2, u_2^c, d_2^c, d_3, u_3, u_3^c, d_3^c, e, \nu\}_L$$

- EW Higgs sector

$$\mathcal{L} \supset \mathbf{Y}_{ij} \mathbf{16}_F^i \mathbf{10}_H \mathbf{16}_F^j$$

$$\mathbf{10}_H = H_u \oplus H_d \oplus T_u \oplus T_d$$

- SO(10) Higgs sector



- Soft Breaking Terms – mSUGRA

$$\mathcal{L}_{soft} = - \mathbf{m}_{16_F}^2 \tilde{16}_F^* \tilde{16}_F - m_{10_H}^2 10_H^* 10_H - \frac{1}{2} m_{1/2} \tilde{X} \tilde{X} \\ - A_0 \mathbf{Y} \tilde{16}_F \tilde{16}_F 10_H - B_0 \mu_H 10_H 10_H + c.c. + \mathcal{L}_\Sigma$$

- Scalar D-terms

$$\Delta m_i^2 = Q_i m_D^2, \quad \text{with} \quad m_D^2 = \frac{1}{2} \frac{(\bar{m}^2 - m^2)}{Q_\Phi} \approx m_{SUSY}^2$$

- EW D-terms

$$\Delta m_i^2 = M_Z^2 \cos 2\beta (I_3^i - Q_i \sin^2 \theta_W)$$

- Boundary conditions at $M_{GUT} \sim 2 \times 10^{16}$ GeV

SU(5)

$$\mathbf{m}_Q^2 = \mathbf{m}_u^2 = \mathbf{m}_e^2 = m_{16_F}^2 \mathbf{1} + m_D^2 \mathbf{1} \rightarrow \mathbf{10}_F,$$

$$\mathbf{m}_L^2 = \mathbf{m}_d^2 = m_{16_F}^2 \mathbf{1} - 3m_D^2 \mathbf{1} \rightarrow \bar{\mathbf{5}}_F,$$

$$\mathbf{m}_\nu^2 = m_{16_F}^2 \mathbf{1} + 5m_D^2 \mathbf{1} \rightarrow \mathbf{1}_F,$$

$$m_{H_d}^2 = m_{10_H}^2 + 2m_D^2 \rightarrow \mathbf{5}_H,$$

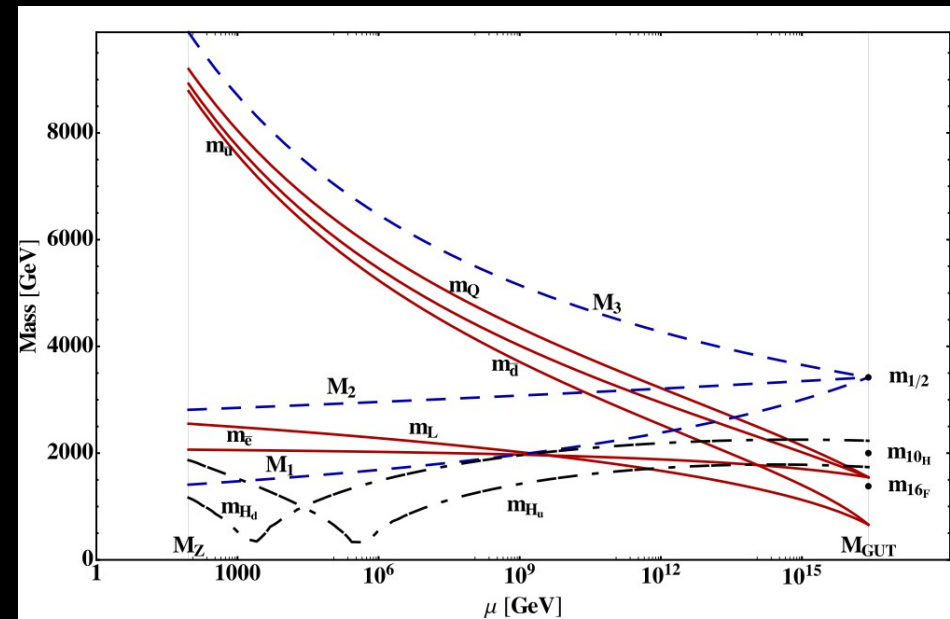
$$m_{H_u}^2 = m_{10_H}^2 - 2m_D^2 \rightarrow \bar{\mathbf{5}}_H,$$

$$A_u = A_d = A_e = A_0,$$

$$M_1 = M_2 = M_3 = m_{1/2}.$$

1-loop Renormalisation Group Equations

$$\begin{aligned}
 m_{\tilde{u}_L}^2 &= m_{16_F}^2 + 1.0m_D^2 + 5.3m_{1/2}^2 - (53.6 \text{ GeV})^2, \\
 m_{\tilde{u}_R}^2 &= m_{16_F}^2 + 0.9m_D^2 + 4.9m_{1/2}^2 - (35.8 \text{ GeV})^2, \\
 m_{\tilde{d}_L}^2 &= m_{16_F}^2 + 1.0m_D^2 + 5.3m_{1/2}^2 - (59.3 \text{ GeV})^2, \\
 m_{\tilde{d}_R}^2 &= m_{16_F}^2 - 2.9m_D^2 + 4.9m_{1/2}^2 - (25.3 \text{ GeV})^2, \\
 m_{\tilde{e}_L}^2 &= m_{16_F}^2 - 3.1m_D^2 + 0.5m_{1/2}^2 - (47.3 \text{ GeV})^2, \\
 m_{\tilde{e}_R}^2 &= m_{16_F}^2 + 1.2m_D^2 + 0.2m_{1/2}^2 - (43.9 \text{ GeV})^2, \\
 m_{\tilde{\nu}_L}^2 &= m_{16_F}^2 - 3.1m_D^2 + 0.5m_{1/2}^2 - (64.5 \text{ GeV})^2.
 \end{aligned}$$



D-term Splitting

- D-term induces splitting between particles in different SU(5) multiplets

$$m_{\tilde{d}_L}^2 - m_{\tilde{d}_R}^2 = 3.9m_D^2 + 0.4m_{1/2}^2 + \mathcal{O}(M_Z^2),$$

$$m_{\tilde{e}_R}^2 - m_{\tilde{e}_L}^2 = 4.3m_D^2 - 0.3m_{1/2}^2 + \mathcal{O}(M_Z^2).$$

- And within the same SU(5) multiplet

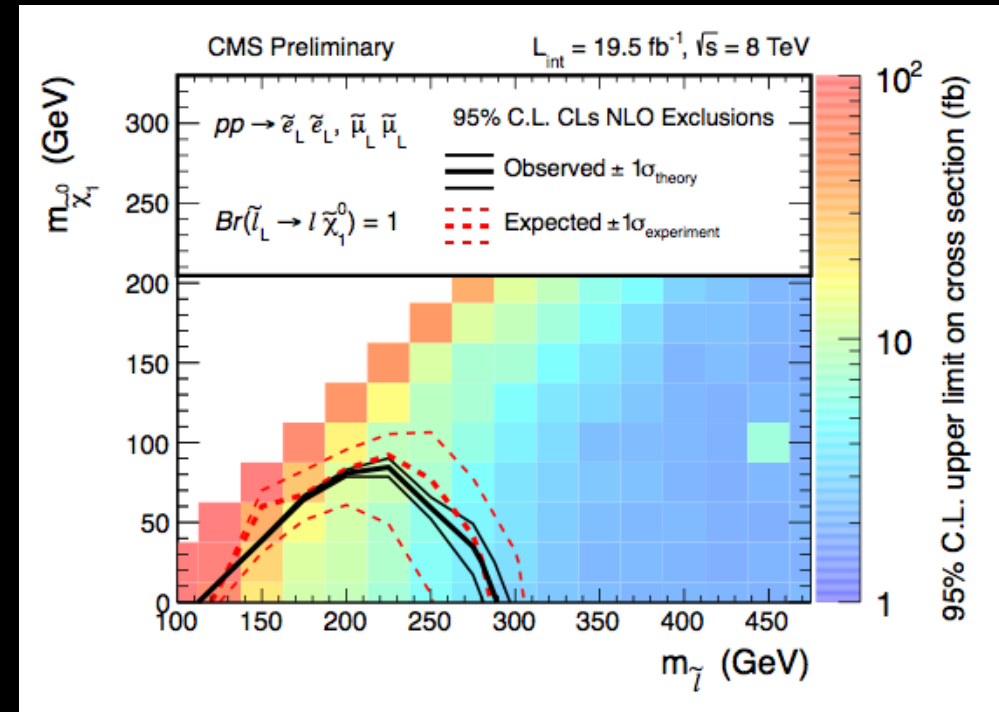
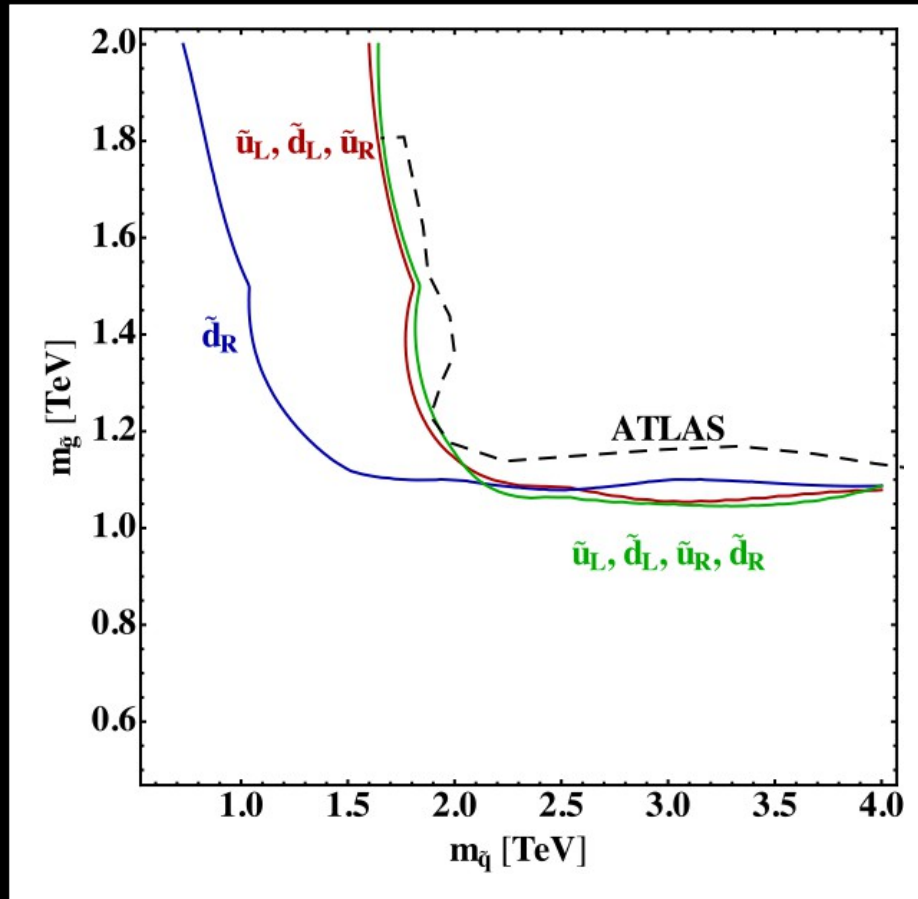
$$m_{\tilde{d}_R}^2 - m_{\tilde{e}_L}^2 = +0.2m_D^2 + 4.4m_{1/2}^2 + \mathcal{O}(M_Z^2),$$

$$m_{\tilde{u}_L}^2 - m_{\tilde{e}_R}^2 = -0.2m_D^2 + 5.1m_{1/2}^2 + \mathcal{O}(M_Z^2),$$

$$m_{\tilde{u}_R}^2 - m_{\tilde{e}_R}^2 = -0.3m_D^2 + 4.7m_{1/2}^2 + \mathcal{O}(M_Z^2).$$

LHC Limits

- Limits on squark and slepton masses



$$m_{\tilde{q}} > 2 \text{ TeV}$$

$$m_{\tilde{\gamma}} > 300 \text{ GeV}$$

- Parameters $\{m_{16_F}^2, m_{10_H}^2, m_{1/2}, m_D^2, A_0, \tan \beta, \text{sign}(\mu)\}$

- Benchmark scenario

$$m_{10_H}^2 = -(3647 \text{ GeV})^2, \quad A_0 = -3140 \text{ GeV},$$
$$\tan \beta = 39, \quad \text{sign}(\mu) = +1.$$

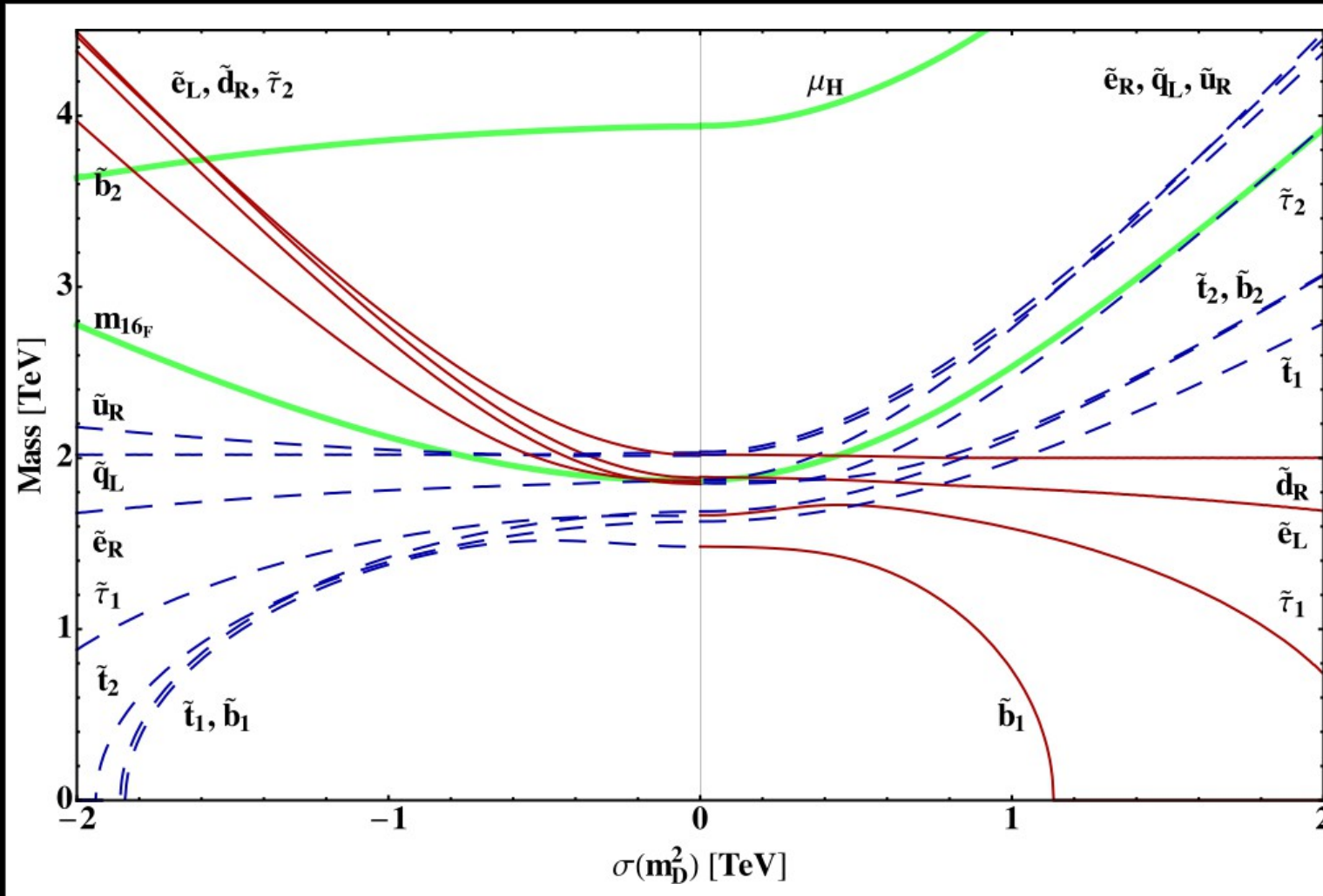
O. Buchmüller et al
(arXiv:1312.5250 [hep-ph])

- Fixed squark and gluino masses

$$m_{\tilde{g}}^2 \sim 1 \text{ TeV} \quad \rightarrow \quad m_{1/2} \sim 389 \text{ GeV},$$

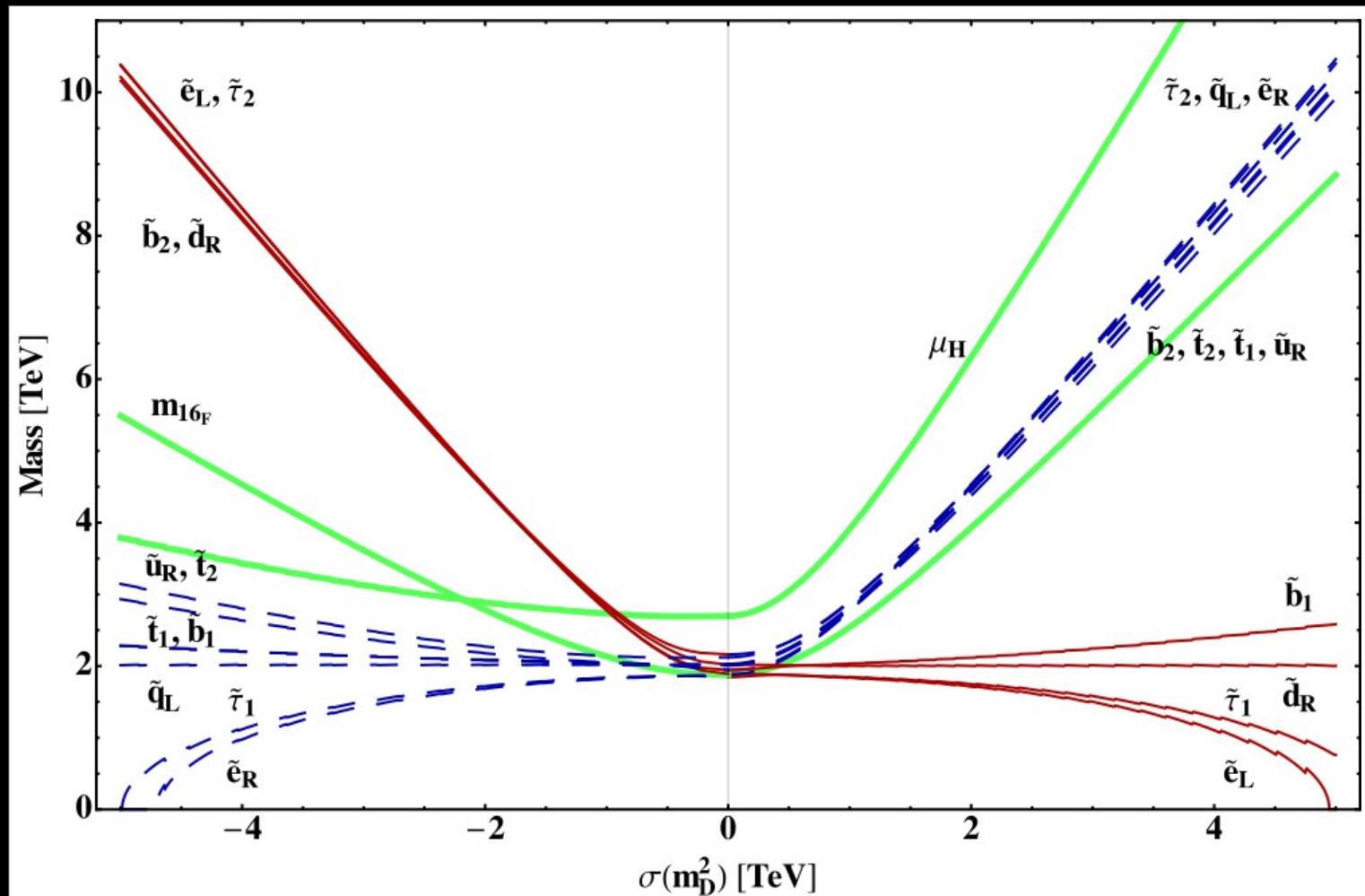
$$m_{\tilde{q}}^2 \sim (2 \text{ TeV})^2 \quad \rightarrow \quad m_{16_F}^2(m_D^2) = m_{\tilde{q}}^2 - c_1 m_D^2 - c_2 m_{1/2}^2 - c_3 + \delta_2.$$

Light 3rd generation



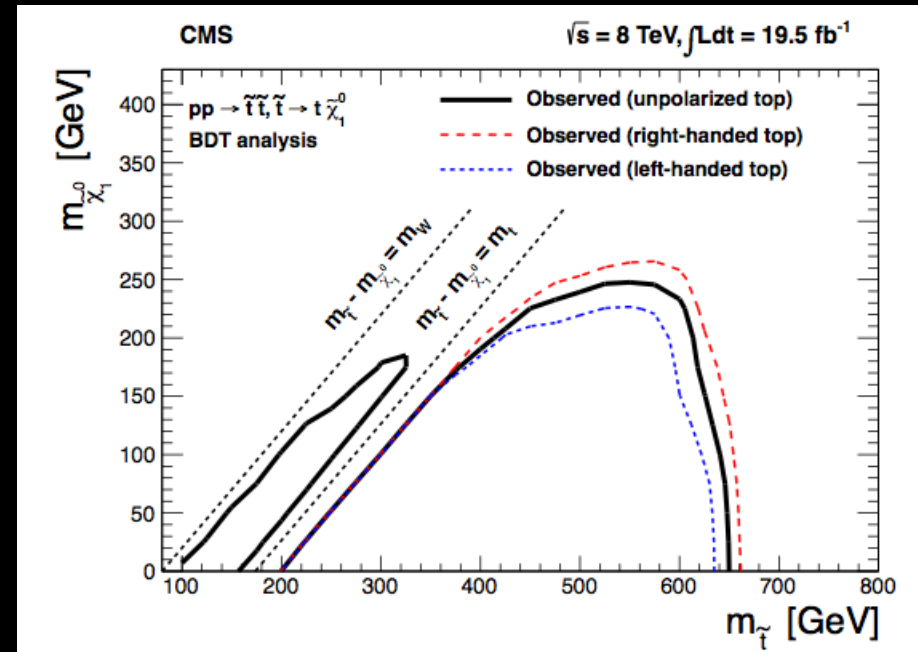
Light 1st generation

$$m_{10H}^2 = -2.1m_{16F}^2, \quad A_0 = 0$$



Summary

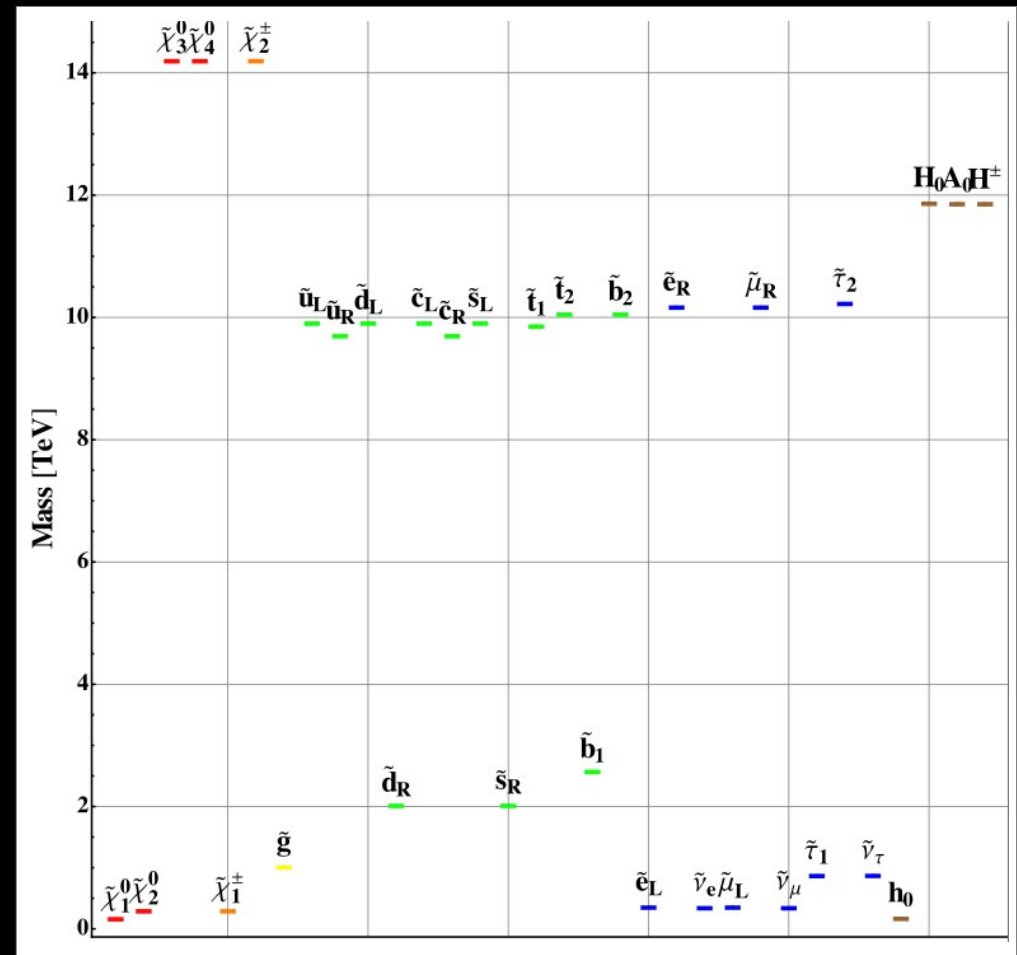
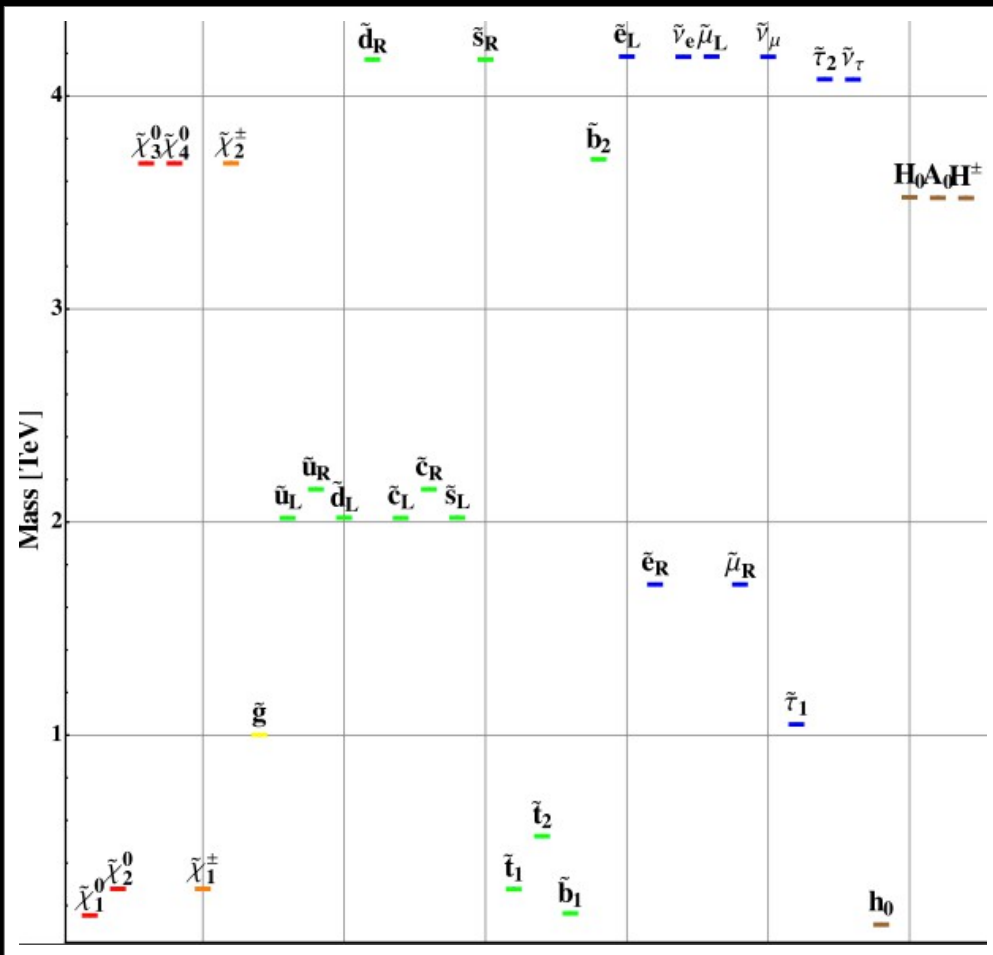
- Light 3rd generation
 - Compressed spectrum
 - Naturalness $\Delta \sim 5$
 - Co-annihilation $m_{\tilde{t}} \sim m_{\tilde{b}} \sim m_{\tilde{\chi}}$
- Light 1st generation sleptons
 - “Unnatural” split spectrum



Example Spectra

Compressed

Split



F. Deppisch, N. Desai & T.G. (arXiv:1403.2312 [hep-ph])