Large D-terms in minimal SUSY SO(10)

Tomás Gonzalo

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Outline

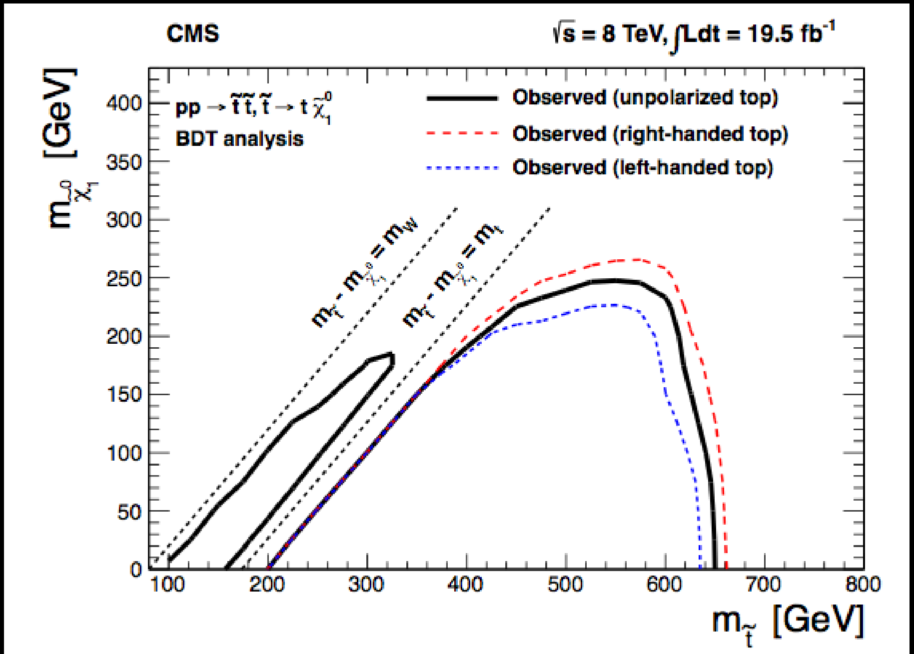
- Motivation
- Minimal SUSY SO(10)
- D – term splitting
- Analysis
- Summary & Example Spectra

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

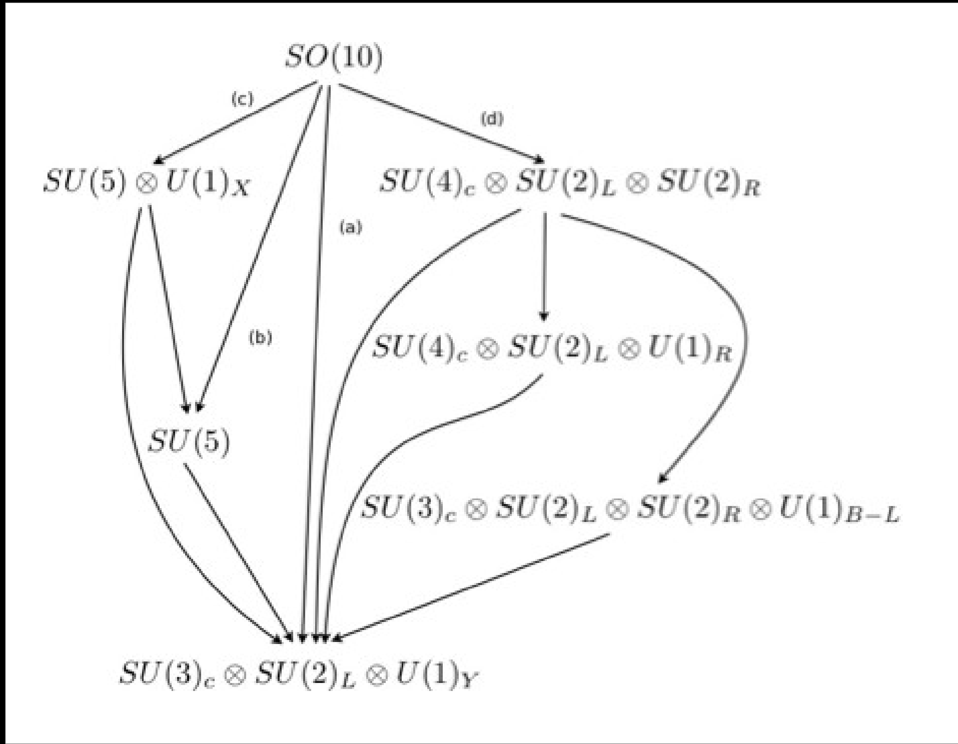
$$\mathbf{16}_F = \{u_1^c, d_1^c, d_1, u_1, \nu^c, e^c, d_2, u_2, u_2^c, d_2^c, d_3, u_3, u_3^c, d_3^c, e, \nu\}_L$$

- 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



Minimal SUSY SO(10)

- Soft Breaking Terms – mSUGRA

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

- Scalar D-terms

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

- c.f. EW D-terms

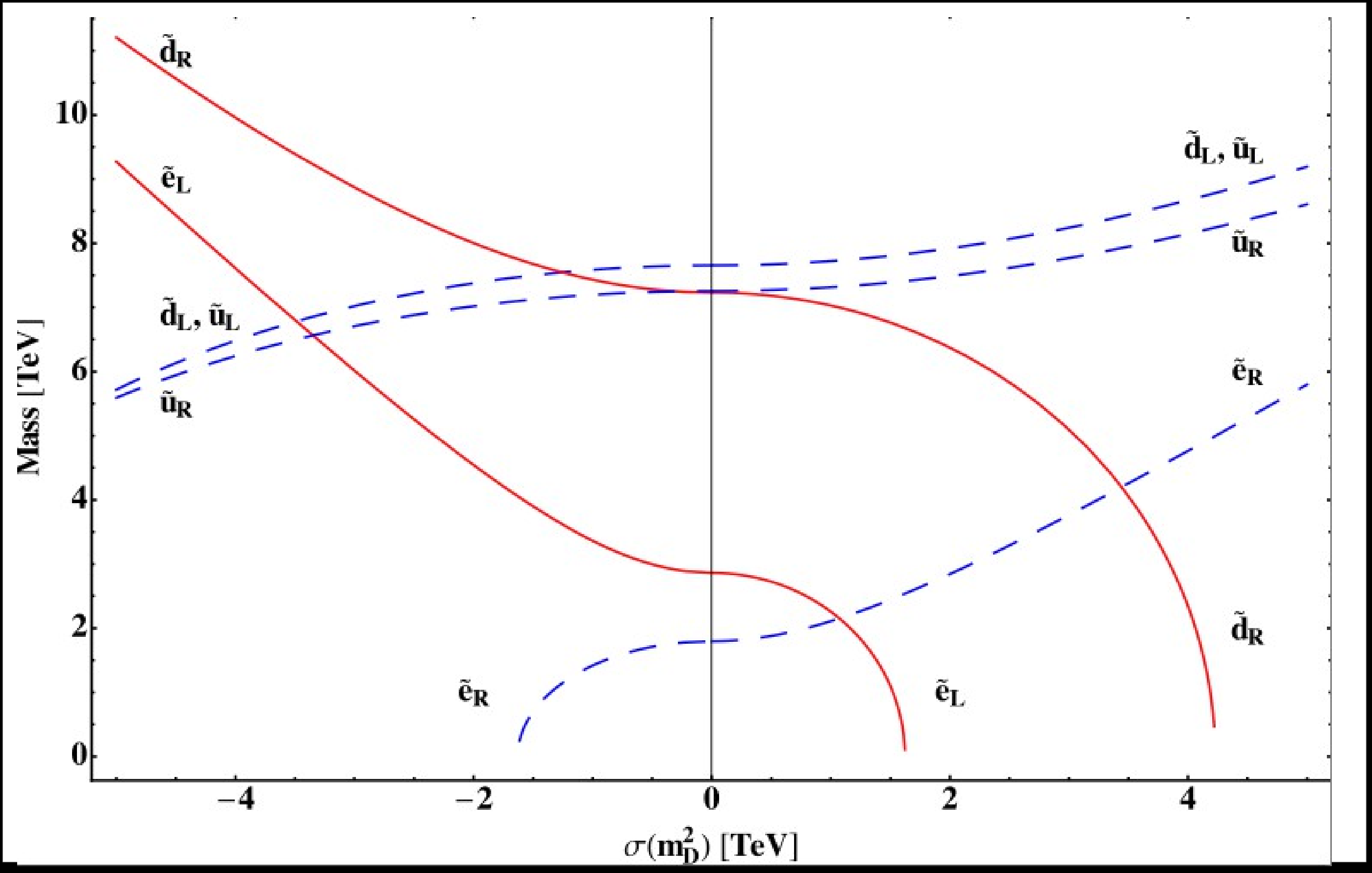
$$\Delta m_i^2 = M_Z^2 \cos 2\beta (I_3^i - Q_i \sin\theta_W)$$

Minimal SUSY SO(10)

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

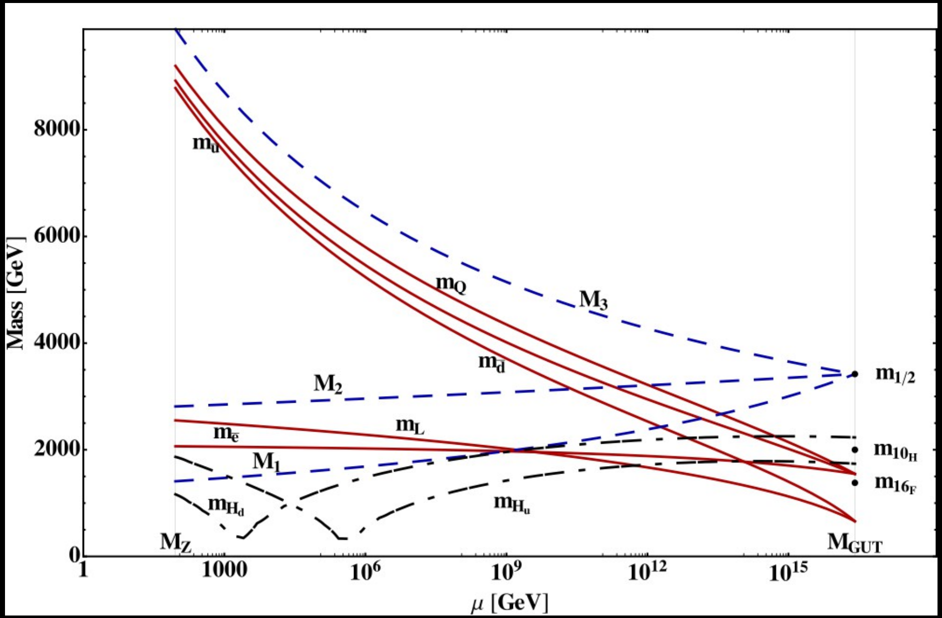
$$
\begin{aligned}
& & & SU(5) \\
\mathbf{m}_Q^2 = \mathbf{m}_u^2 = \mathbf{m}_e^2 &= m_{16_F}^2 \mathbf{1} + \ \ m_D^2 \mathbf{1} & & \to \mathbf{10}_F, \\
\mathbf{m}_L^2 = \mathbf{m}_d^2 &= m_{16_F}^2 \mathbf{1} - 3 m_D^2 \mathbf{1} & & \to \bar{\mathbf{5}}_F, \\
\mathbf{m}_\nu^2 &= m_{16_F}^2 \mathbf{1} + 5 m_D^2 \mathbf{1} & & \to \mathbf{1}_F, \\
m_{H_d}^2 &= m_{10_H}^2 \ \ + 2 m_D^2 & & \to \mathbf{5}_H, \\
m_{H_u}^2 &= m_{10_H}^2 \ \ - 2 m_D^2 & & \to \bar{\mathbf{5}}_H, \\
A_u = A_d = A_e &= A_0, & & \\
M_1 = M_2 = M_3 &= m_{1/2}. & &
\end{aligned}
$$

Minimal SUSY SO(10)



1-loop Renormalisation Group Equations

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



D-term Splitting

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

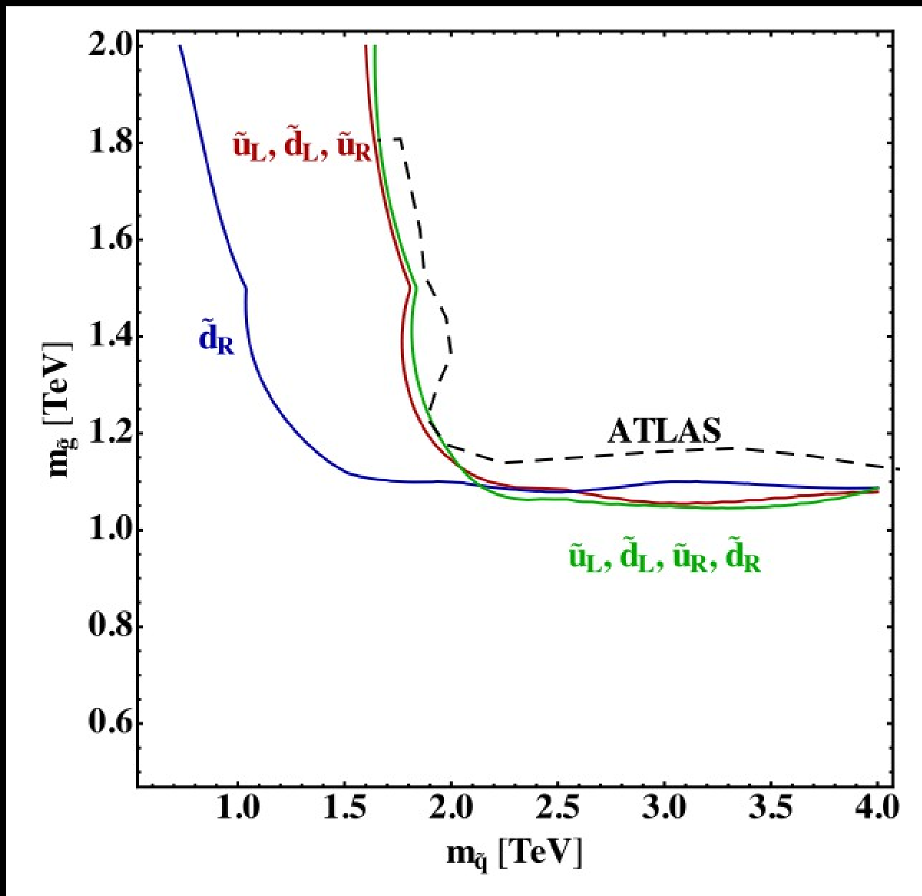
$$m^2_{\tilde{d}_L} - m^2_{\tilde{d}_R} = 3.9 m_D^2 + 0.4 m_{1/2}^2 + \mathcal{O}(M_Z^2),$$
$$m^2_{\tilde{e}_R} - m^2_{\tilde{e}_L} = 4.3 m_D^2 - 0.3 m_{1/2}^2 + \mathcal{O}(M_Z^2).$$

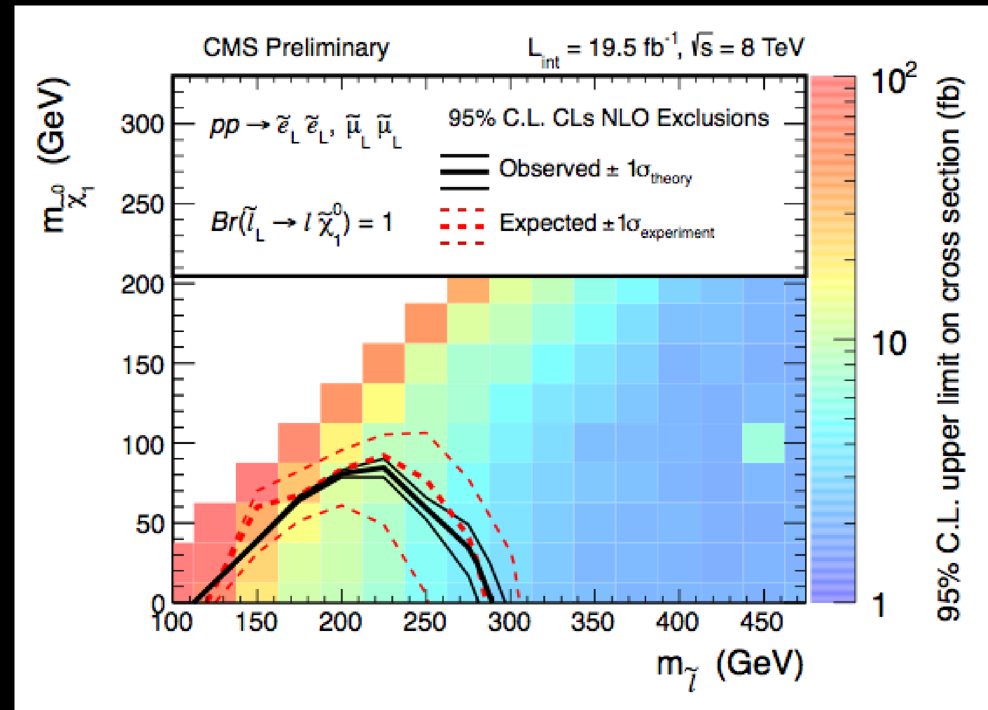
- And within the same SU(5) multiplet

$$m^2_{\tilde{d}_R} - m^2_{\tilde{e}_L} = +0.2 m_D^2 + 4.4 m_{1/2}^2 + \mathcal{O}(M_Z^2),$$
$$m^2_{\tilde{u}_L} - m^2_{\tilde{e}_R} = -0.2 m_D^2 + 5.1 m_{1/2}^2 + \mathcal{O}(M_Z^2),$$
$$m^2_{\tilde{u}_R} - m^2_{\tilde{e}_R} = -0.3 m_D^2 + 4.7 m_{1/2}^2 + \mathcal{O}(M_Z^2).$$

LHC Limits

- Limits on squark and slepton masses





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

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

Analysis

- Parameters $\{m^2_{16_F}, m^2_{10_H}, m_{1/2}, m^2_D, A_0, \tan\beta, \mathrm{sign}(\mu)\}$
- Benchmark scenario

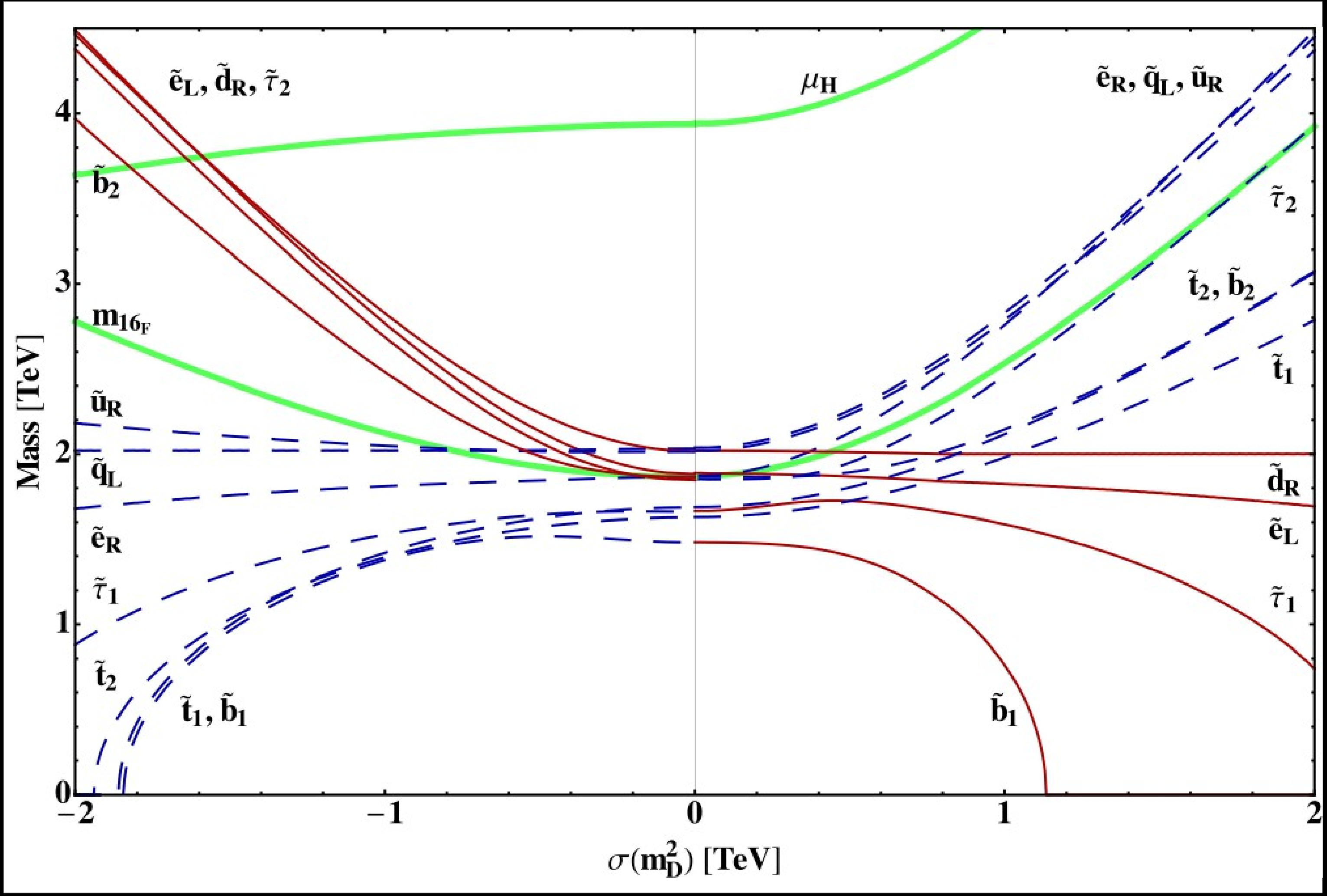
$$m^2_{10_H} = -(3647\ \mathrm{GeV})^2, \quad A_0 = -3140\ \mathrm{GeV},$$
$$\tan\beta = 39, \quad \mathrm{sign}(\mu) = +1.$$

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

- Fixed squark and gluino masses

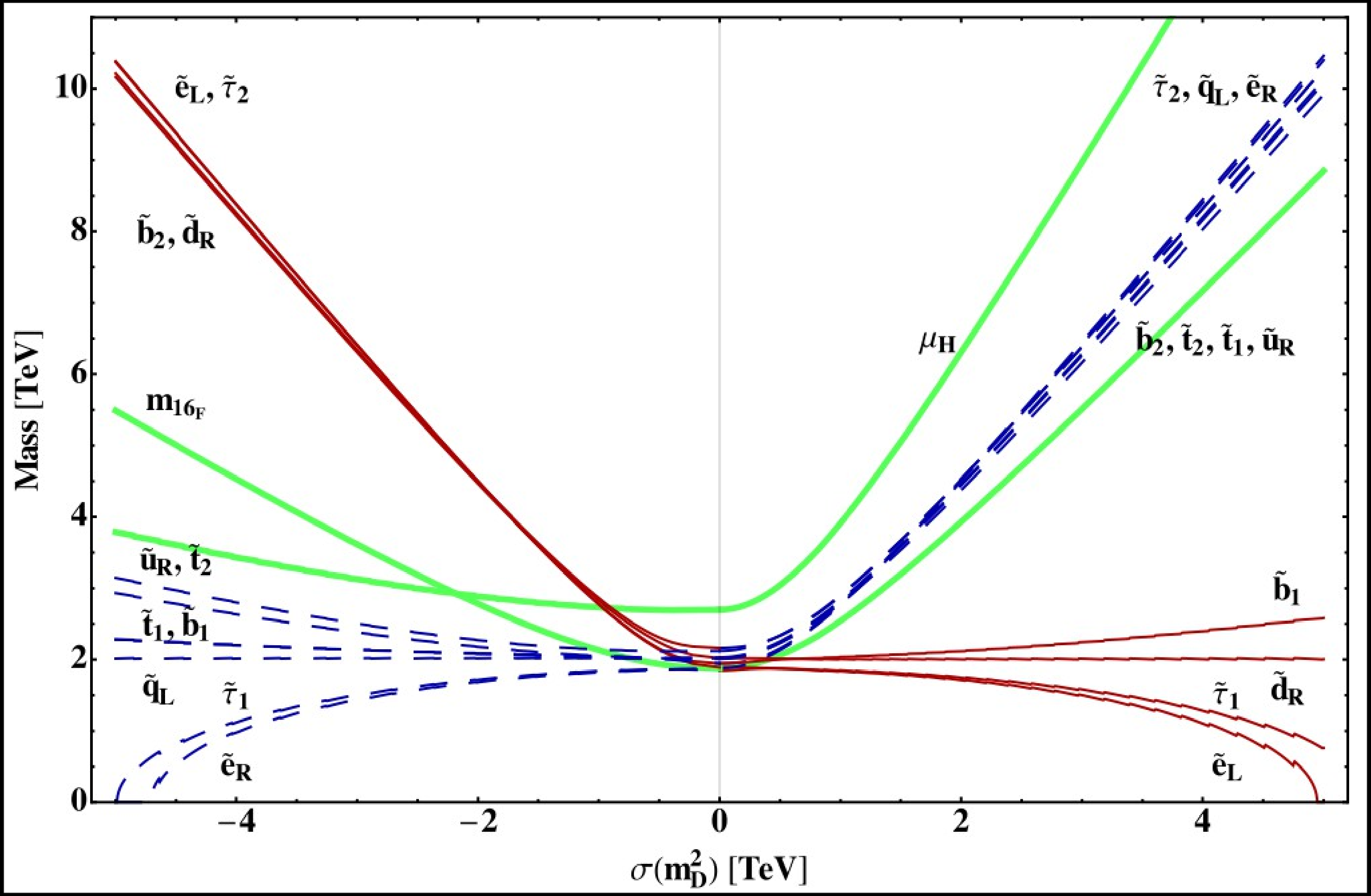
$$m^2_{\tilde{g}} \sim 1\ \mathrm{TeV} \quad \rightarrow m_{1/2} \sim 389\ \mathrm{GeV},$$
$$m^2_{\tilde{q}} \sim (2\ \mathrm{TeV})^2 \rightarrow m^2_{16_F}(m^2_D) = m^2_{\tilde{q}} - c_1 m^2_D - c_2 m^2_{1/2} - c_3 + \delta_2.$$

Light 3rd generation



Light 1st generation

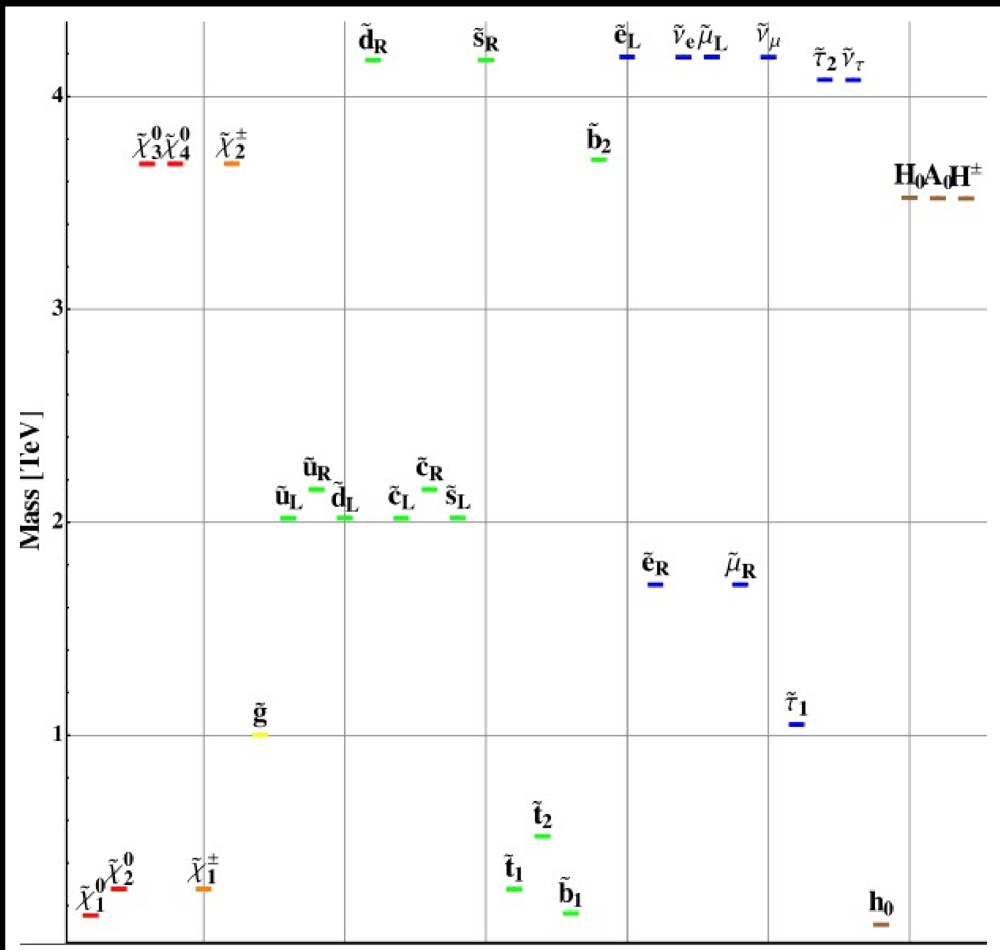
$$m^2_{10_H} = -2.1 m^2_{16_F}, \quad A_0 = 0$$



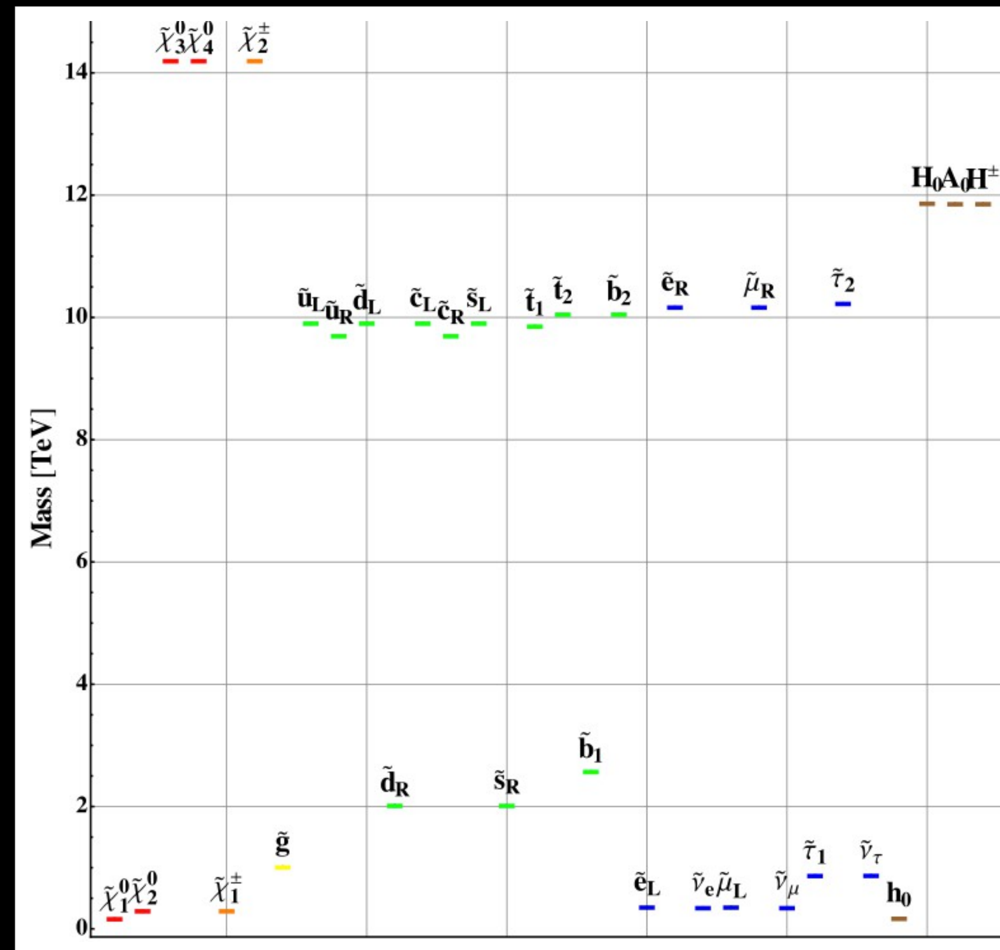
Example Spectra

UCL

Compressed

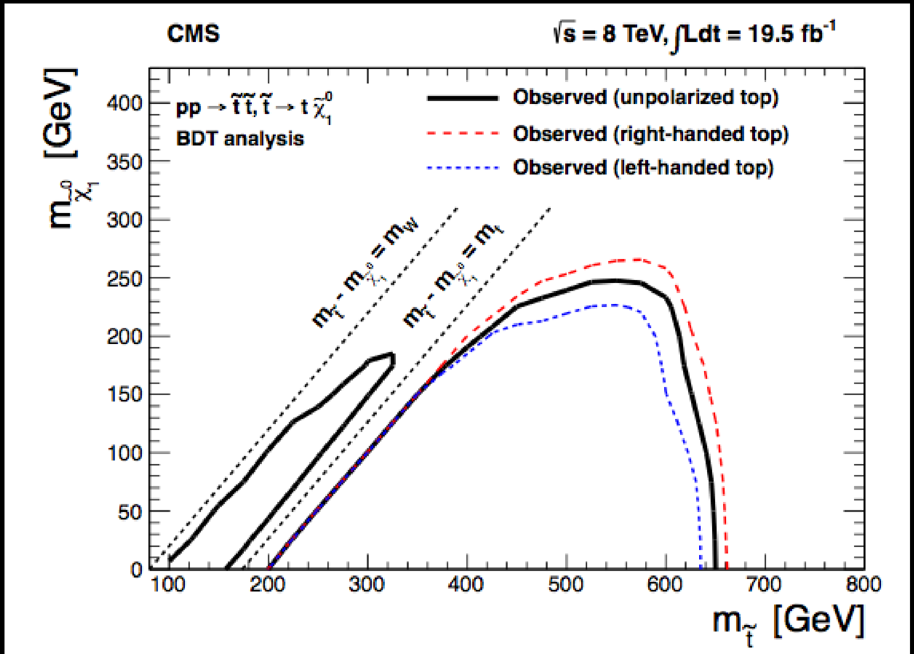


Split



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

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

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