Hybrid Mediation of Electroweak SUSY

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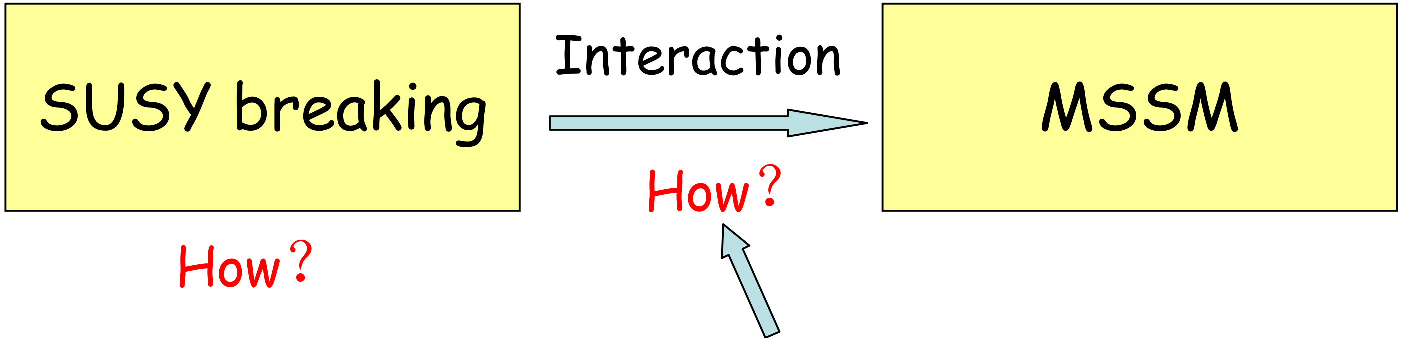
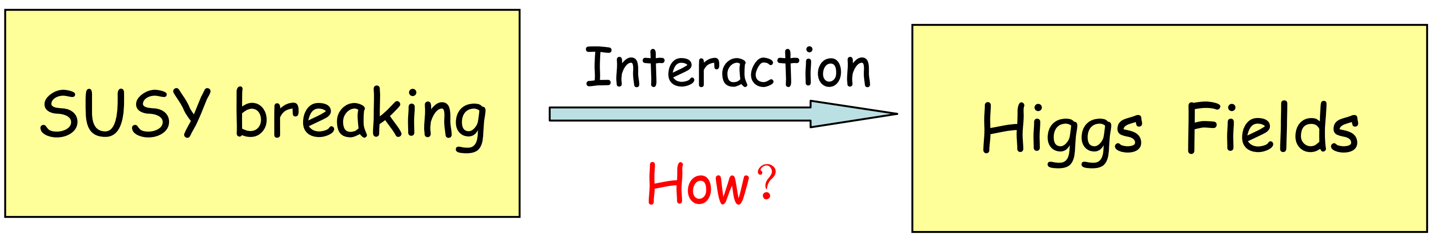
- SUSY breaking and its mediation
- Hybrid Mediation Supersymmetry
- Phenomenology and DM properties

SUSY breaking and its mediation



This is the important part and the difficult part. This determines the pattern of the low energy parameters.

In particular,



This part is very important because...

This is relate to whole motivation of SUSY. The successful EWSB needs this communication to be carefully done. See Zhaofeng Kang

μ-problem

SUSY (Higgsino mass)

$$V(H) = (m_{H_u}^2 + \mu^2)|H_u|^2 + (m_{H_d}^2 + \mu^2)|H_d|^2$$
$$+ B\mu H_u H_d + \text{h.c.}$$
$$+ \frac{g^2}{8}(|H_u|^2 - |H_d|^2)^2$$

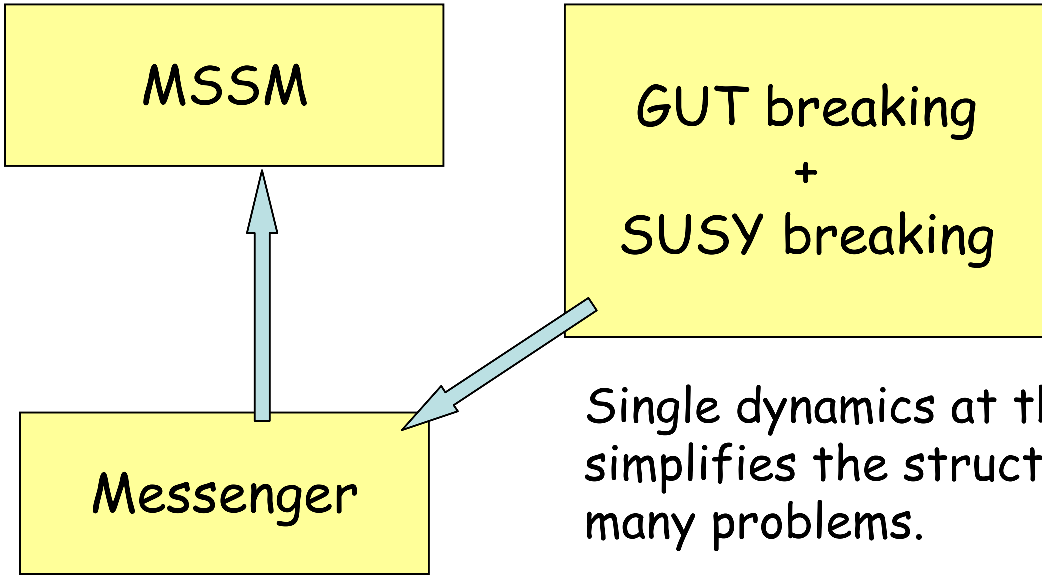
SUSY breaking

For natural EWSB, we need $\mu^2 \sim m_{H_u}^2 \sim m_{H_d}^2 \sim m_W^2$

- Gravity, gauge & anomaly mediation and their problem

	gauge mediatoin $m_{3/2} \ll 100\ \text{GeV}$	gravity mediation $m_{3/2} \sim 100\ \text{GeV}$	anomaly mediation $m_{3/2} \sim 10 - 100\ \text{TeV}$
μ -problem	✖	OK	✖
CP problem	OK	✖	?
Flavor problem	OK	✖	OK
Moduli problem	?	✖	OK
Tachyon	OK	OK	✖

Hybrid Mediation of Supersymmetry



Single dynamics at the GUT scale, this simplifies the structure and naturally solves many problems.

- Gravity-Gauge Mediation
- Gravity-Anomaly Mediation
- Gauge-Anomaly Mediation

●Mu g-2 Anomaly

●To explain (g-2) and 125 GeV simultaneously, favor large splitting between squarks and sleptons

$$\Delta a_\mu = (a_\mu)_{\rm exp} - (a_\mu)_{\rm SM} = (28.6 \pm 8.0) \times 10^{-10}$$

●Deviation resulted from new particles

$$\Delta a_\mu \sim \left(\frac{g^2}{16\pi^2}\right)\left(\frac{m_\mu}{m_{\rm NP}}\right)^2 \sim 20.7 \times 10^{-10}\left(\frac{120\ {\rm GeV}}{m_{\rm NP}}\right)^2\left(\frac{g}{0.65}\right)^2$$

Gravity-Gauge Mediation

- SUSY breaking spurion $\langle X \rangle = M + \theta^2 F$

- Gauge Mediation

  Type-I $W_{\rm mess} = \lambda X \Phi_G \Phi_G$

  Type-II $W_{\rm mess} = \lambda X \Phi_D \Phi_D^c$

- Boundary Conditions at GUT Scale

$$\tilde{m}_{ij}^2 = m_0^2 \delta_{ij}, \; T_{u,d,e} = A_0 Y_{u,d,e}, \; M_{1,2,3} = m_{1/2}$$

- Boundary Conditions at Messenger Scale: Type-I

$$M_i = \frac{g_i^2}{16\pi^2} n_G \Lambda a_i$$

$$m_{\tilde{l}}^2 = m_{\tilde{e}}^2 = m_{H_u}^2 = m_{H_d}^2 = 0\,,$$

$$m_{\tilde{u}}^2 = m_{\tilde{d}}^2 = \frac{g_3^4}{32\pi^4} n_G \Lambda^2 f\left(\frac{\Lambda}{M_{\rm mess}}\right)$$

$$m_{\tilde{q}}^2 = \frac{3 g_3^4}{16\pi^4} n_G \Lambda^2 f\left(\frac{\Lambda}{M_{\rm mess}}\right).$$

● Boundary Conditions at Messenger Scale: Type-I

$$M_1 = \frac{g_1^2}{40\pi^2} n_d \Lambda g \left(\frac{\Lambda}{M_{\rm mess}} \right) ,$$

$$M_3 = \frac{g_3^2}{40\pi^2} n_d \Lambda g \left(\frac{\Lambda}{M_{\rm mess}} \right) ,$$

$$m_{\tilde{q}}^2 = \frac{1}{128\pi^4} \left(\frac{1}{150} g_1^4 + \frac{4}{3} g_3^4 \right) n_d \Lambda^2 f \left(\frac{\Lambda}{M_{\rm mess}} \right)$$

$$m_{\tilde{u}}^2 = \frac{1}{128\pi^4} \left(\frac{8}{75} g_1^4 + \frac{4}{3} g_3^4 \right) n_d \Lambda^2 f \left(\frac{\Lambda}{M_{\rm mess}} \right)$$

$$m_{\tilde{d}}^2 = \frac{1}{128\pi^4} \left(\frac{2}{75} g_1^4 + \frac{4}{3} g_3^4 \right) n_d \Lambda^2 f \left(\frac{\Lambda}{M_{\rm mess}} \right)$$

$$m_{\tilde{l}}^2 = m_{H_u}^2 = m_{H_d}^2 = \frac{3 g_1^4}{128\pi^4} n_d \Lambda^2 f \left(\frac{\Lambda}{M_{\rm mess}} \right)$$

$$m_{\tilde{e}}^2 = \frac{g_1^4}{3200\pi^4} n_d \Lambda^2 f \left(\frac{\Lambda}{M_{\rm mess}} \right) .$$

● Free parameters

$$\{m_0,\ m_{12},\ A_0,\ {\rm sign}(\mu),\ \tan\beta,\ \Lambda,\ M_{\rm mess},\ n_{G/d}\}$$

- Parameter space

$$\Lambda \in [10^4,\ 10^6]\ \mathrm{GeV}\ , \quad m_0 \in [200,\ 1000]\ \mathrm{GeV}$$

$$m_{1/2} = 300\ \mathrm{GeV},\ A_0 = 0,\ \tan\beta = 20,\ n_{G/d} = 1 \quad \mathrm{sign}(\mu) = 1$$

- The higgs mass $123\mathrm{GeV} \leq m_h \leq 127\mathrm{GeV}$

- LEP bounds and following B physics constraints

$$1.6 \times 10^{-9} \leq \mathrm{BR}(B_s \to \mu^+\mu^-) \leq 4.2 \times 10^{-9}\ (2\sigma)$$

$$2.99 \times 10^{-4} \leq \mathrm{BR}(b \to s\gamma) \leq 3.87 \times 10^{-4}\ (2\sigma)$$

$$7.0 \times 10^{-5} \leq \mathrm{BR}(B_u \to \tau\nu_\tau) \leq 1.5 \times 10^{-4}\ (2\sigma)$$

- Muon g-2

$$4.7 \times 10^{-10} \leq \Delta a_\mu \leq 52.7 \times 10^{-10}\ (3\sigma)$$

- LHC mass limits

$$m_{\tilde{g}} > 1800\ \mathrm{GeV}$$

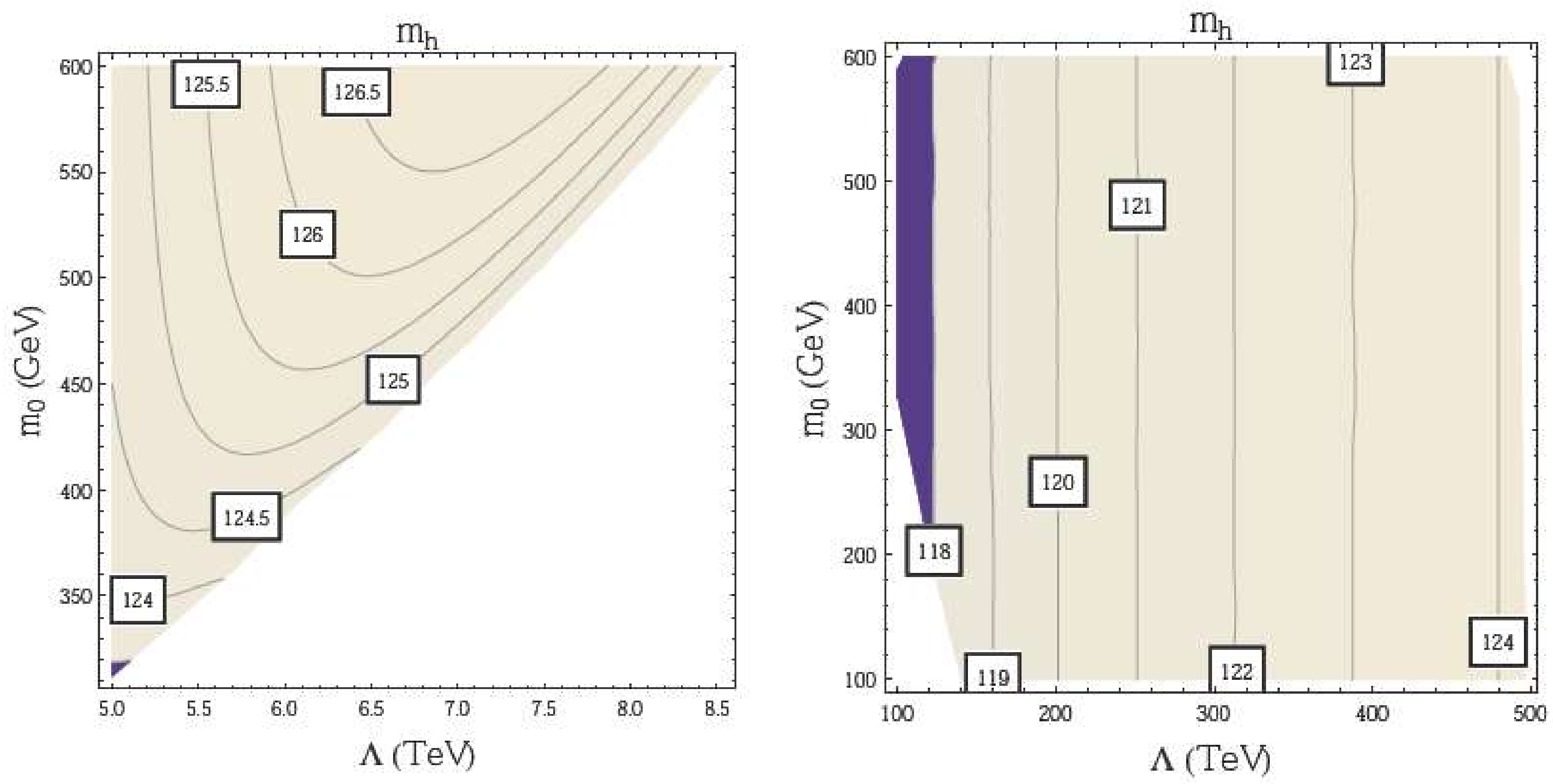
$$m_{\tilde{t}_1} > 850\ \mathrm{GeV}$$

$$m_{\tilde{b}_1} > 840 - 1000\ \mathrm{GeV}$$

$$m_{\tilde{q}} > 1000 - 1400\ \mathrm{GeV}$$

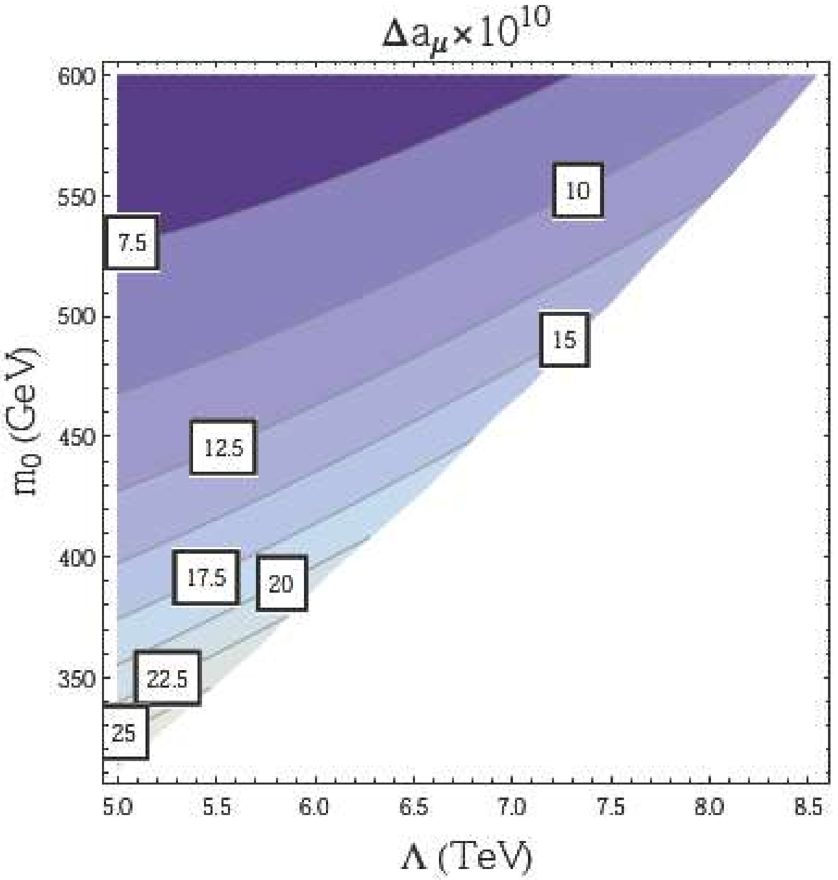
Higgs mass

Type-I Type-II

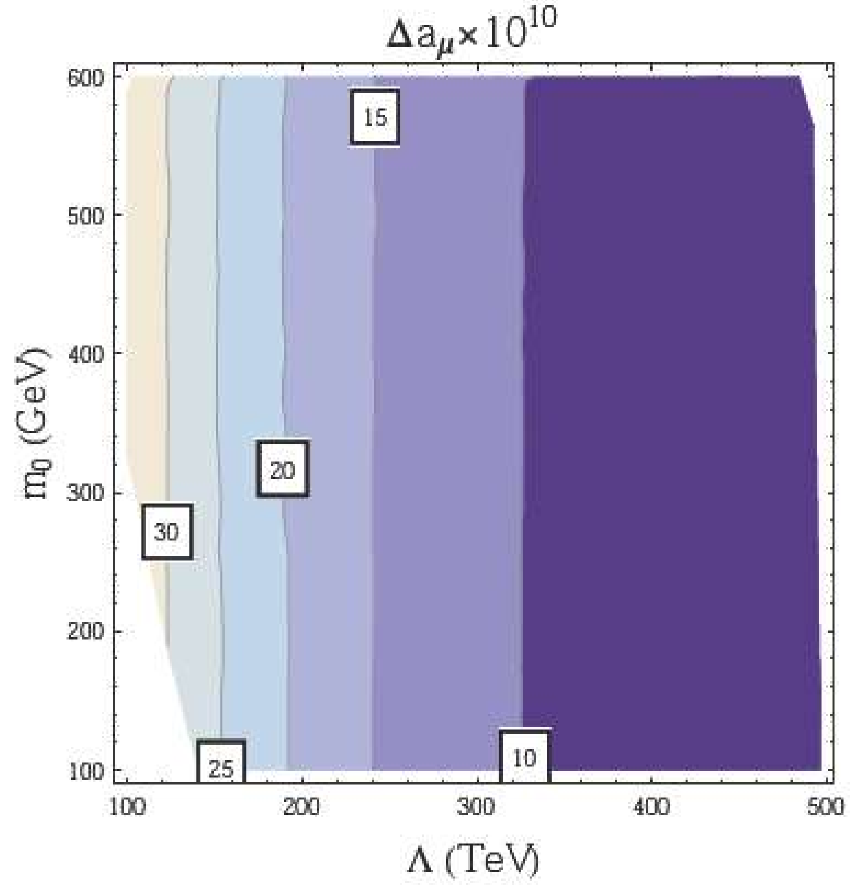


Muon g-2 anomaly

Type-I

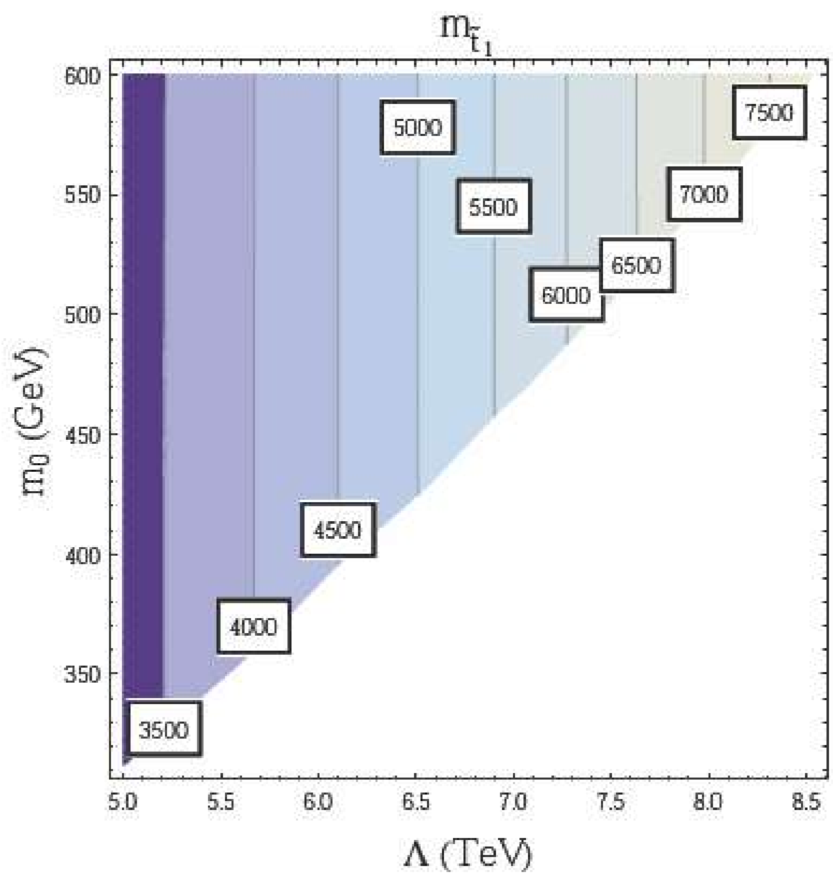


Type-II

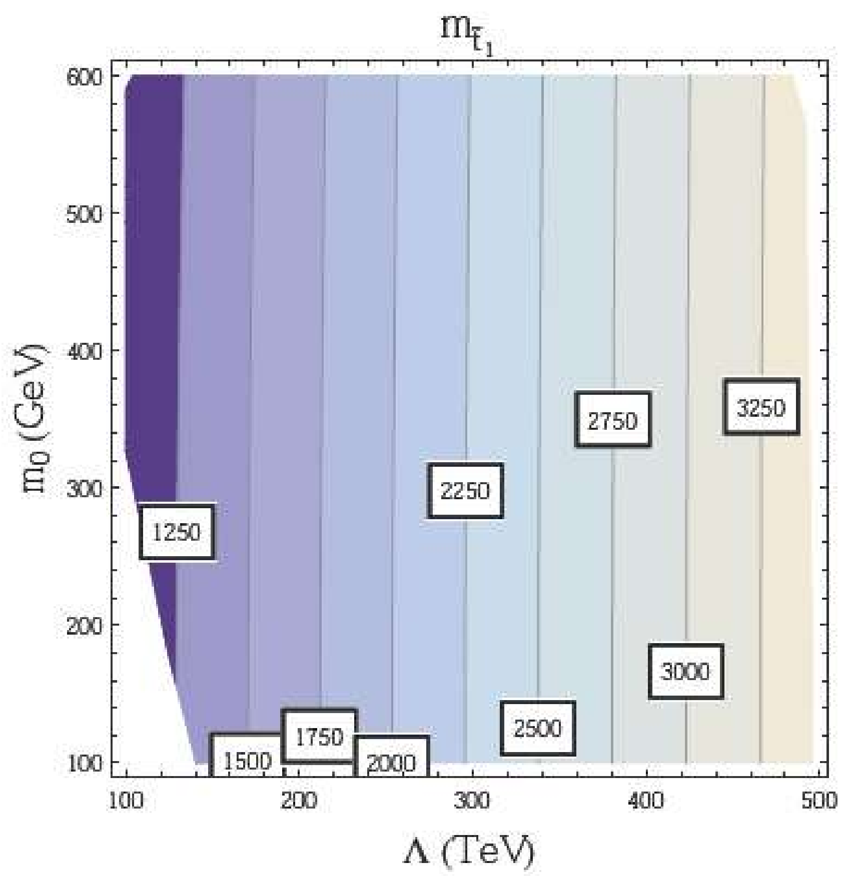


● Stop masses

Type-I

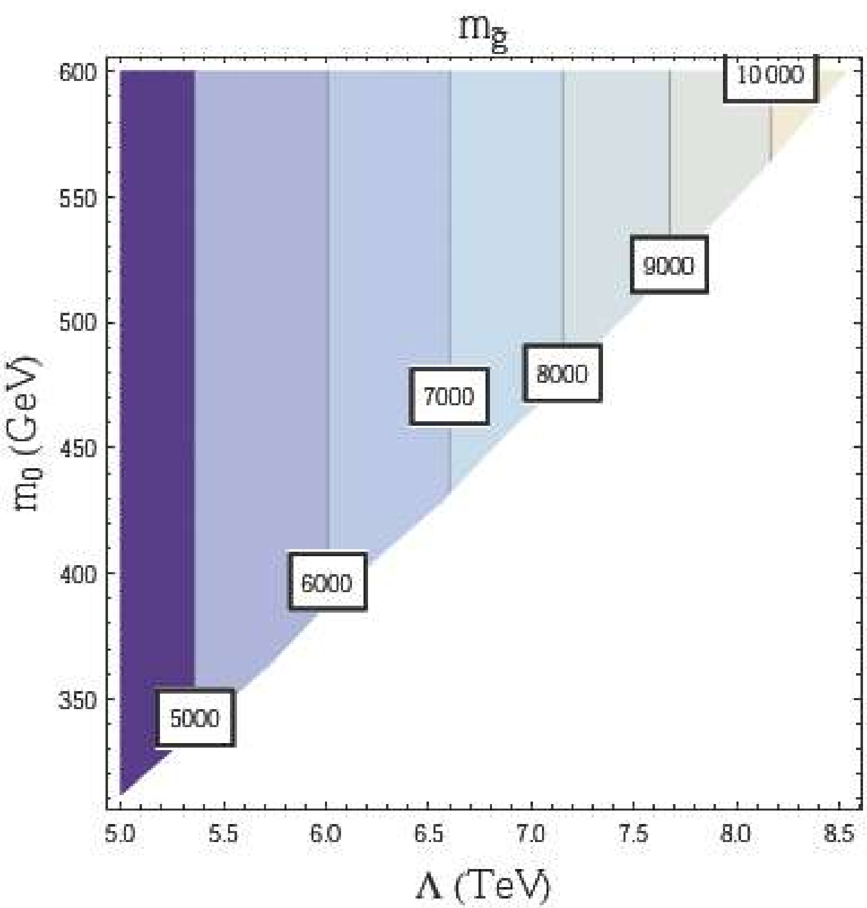


Type-II

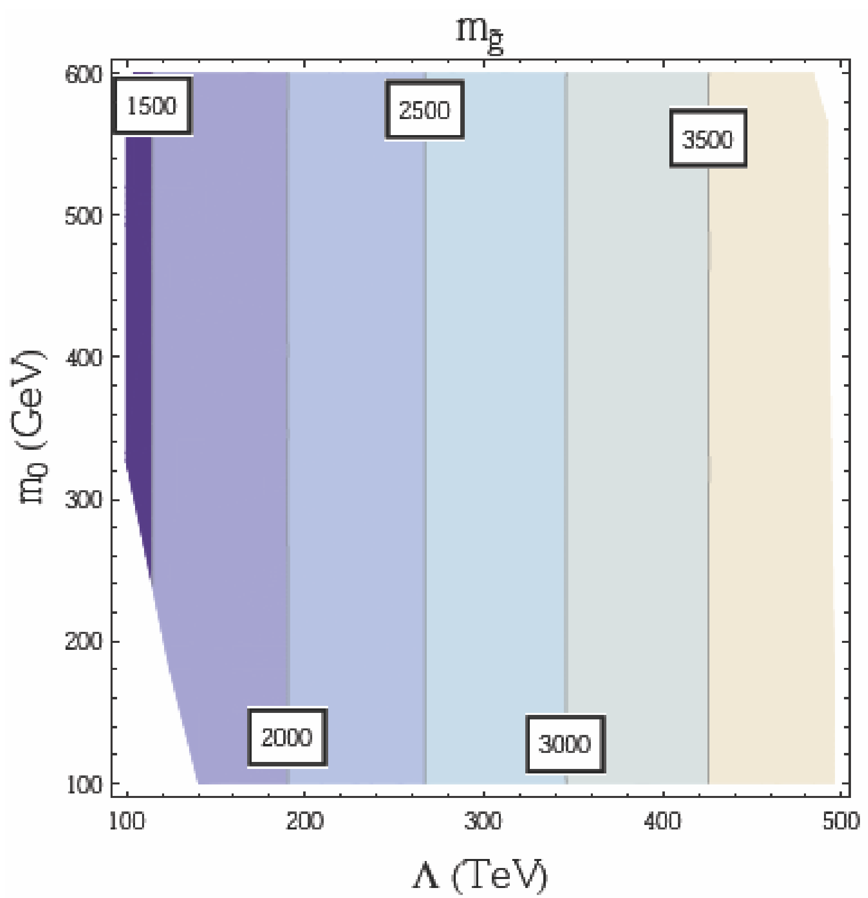


●Gluino masses

Type-I



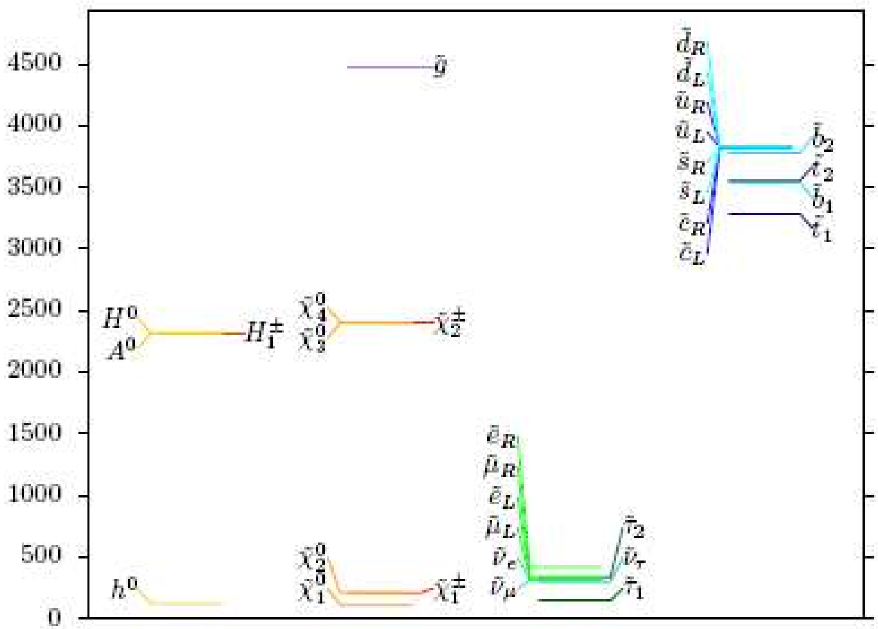
Type-II



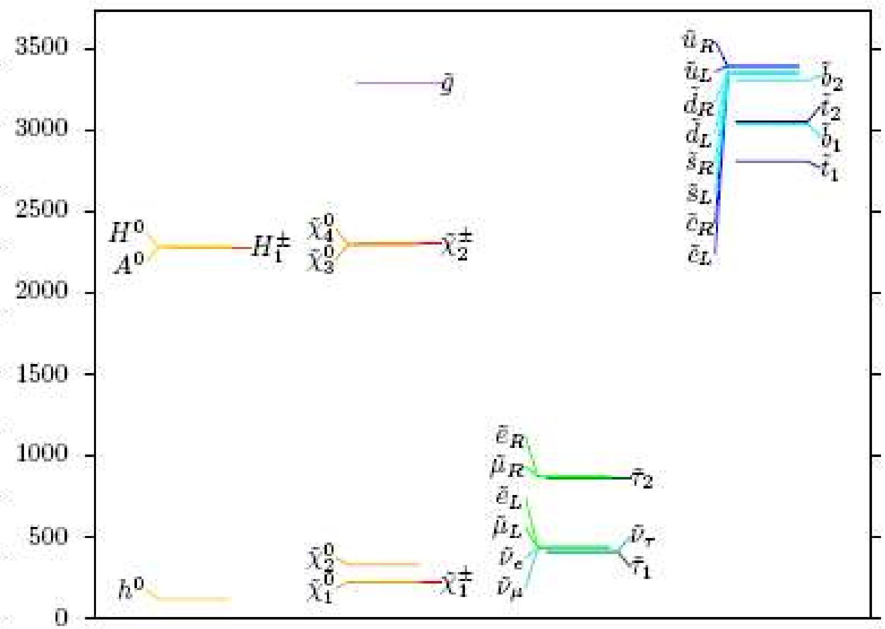
Benchmark Points & Example Spectra

Model	m_0	Λ	m_h	$m_{\tilde{t}_1}$	$m_{\tilde{g}}$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_1^\pm}$	Δa_μ
Type-I	312	5×10^3	123.4	3284	4482	113	213	2.8×10^{-9}
Type-II	428	3.9×10^5	123	2806	3284	226	227	7.6×10^{-10}

Type-I



Type-II



Gravity-Anomaly Mediation

gaugino masses

$$M_1 = \frac{33}{5}\frac{g_1^2 m_{32}}{16\pi^2} \sim \frac{m_{32}}{120} \,,$$
$$M_2 = \frac{g_2^2 m_{32}}{16\pi^2} \sim \frac{m_{32}}{360} \,,$$
$$M_3 = -3\frac{g_3^2 m_{32}}{16\pi^2} \sim -\frac{m_{32}}{40}$$

wino dark matter

trilinear soft terms

$$T_{ijk} = \frac{1}{2}(\gamma_i + \gamma_j + \gamma_k) y_{ijk} \frac{F}{M}$$

sfermion masses

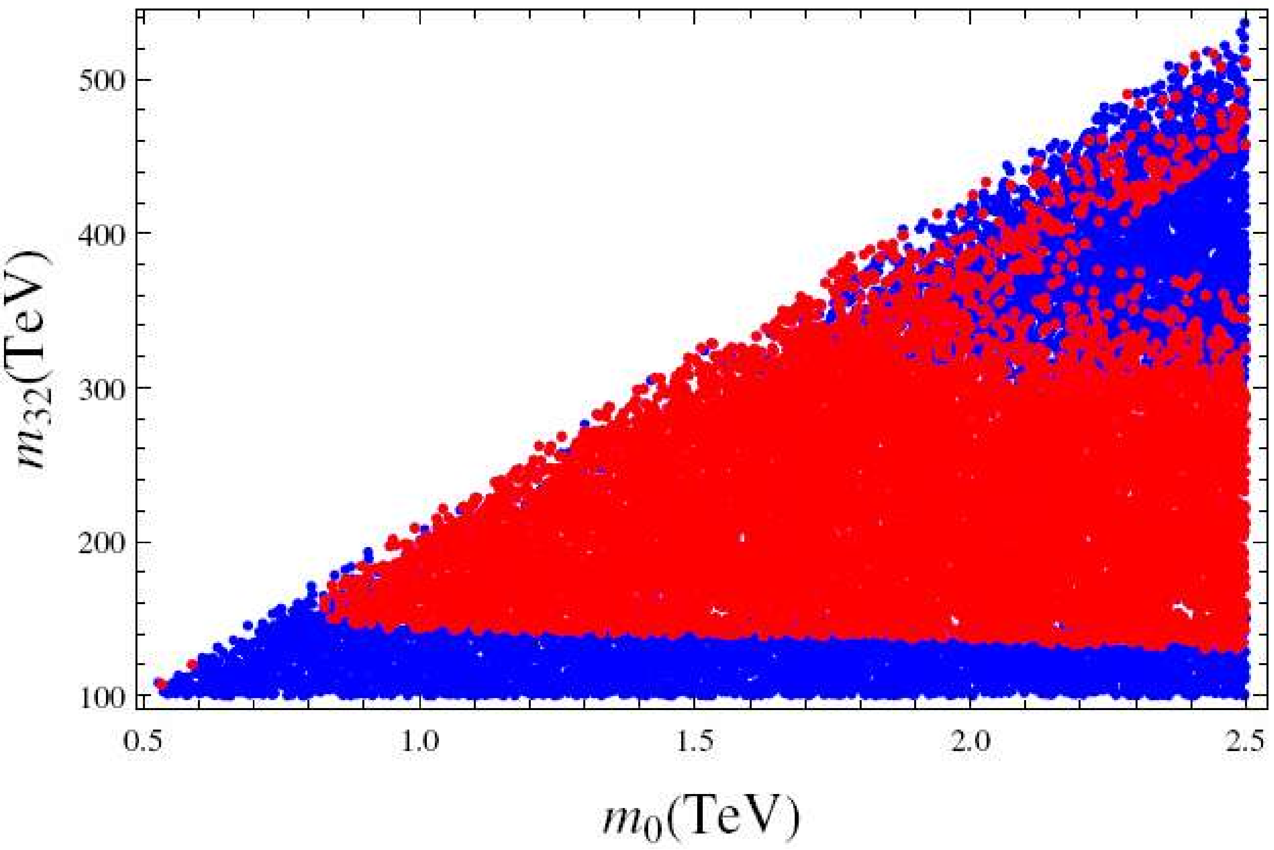
$$m_{u_3}^2 = \frac{m_{32}^2 \left(-\frac{88 g_1^4}{25} + 8 g_3^4 + 2\beta_t y_t\right)}{256\pi^4} \,,$$
$$m_{d_3}^2 = \frac{m_{32}^2 \left(2\beta_b y_b - \frac{22 g_1^4}{25} + 8 g_3^4\right)}{256\pi^4} \,,$$
$$m_{q_3}^2 = \frac{m_{32}^2 \left(\beta_b y_b - \frac{11 g_1^4}{25} - \frac{3 g_2^4}{2} + 8 g_3^4 + \beta_t y_t\right)}{256\pi^4}$$
$$m_{L_3}^2 = \frac{m_{32}^2 \left(-\frac{99 g_1^4}{50} - \frac{3 g_2^4}{2} + \beta_\tau y_\tau\right)}{256\pi^4} \,,$$
$$m_{e_3}^2 = \frac{m_{32}^2 \left(2\beta_\tau y_\tau - \frac{198 g_1^4}{25}\right)}{256\pi^4} \,,$$
$$m_{H_d}^2 = \frac{m_{32}^2 \left(-\frac{99 g_1^4}{50} - \frac{3 g_2^4}{2} + \beta_\tau y_\tau + 3\beta_b y_b\right)}{256\pi^4} \,,$$
$$m_{H_u}^2 = \frac{m_{32}^2 \left(-\frac{99 g_1^4}{50} - \frac{3 g_2^4}{2} + 3\beta_t y_t\right)}{256\pi^4} \,.$$

- Free parameters

$$\{m_0, m_{32}, \tan\beta, \mathrm{Sign}(\mu)\}$$

- Parameter space

$$m_0 \in [500,\ 2500]\ \mathrm{GeV}\ , \quad m_{32} \in [10^5,\ 10^6]\ \mathrm{GeV}\ , \tan\beta \in [10, 30]$$



● Mixed axion-wino dark matter

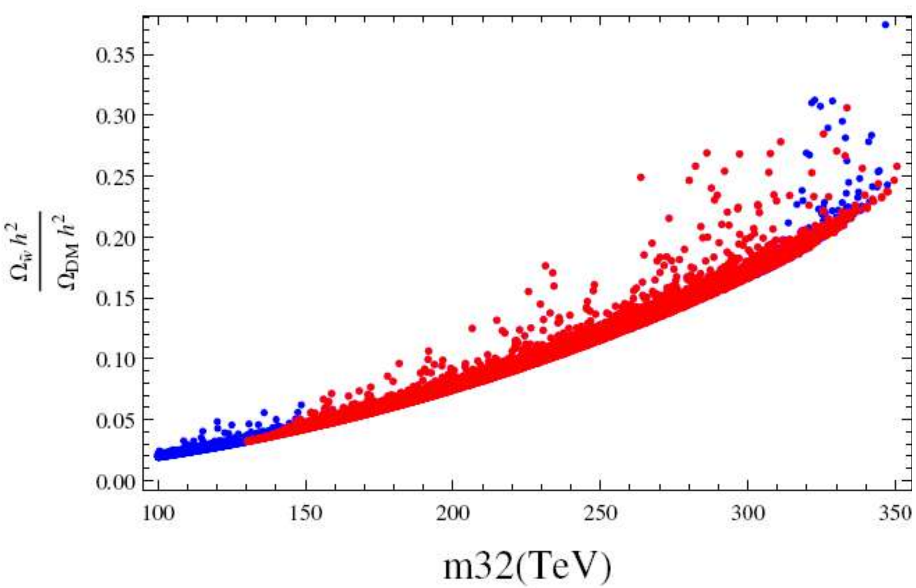
● wino WIMP relic $\Omega_{\tilde{W}} h^2 \sim 0.12(M_2/2.5\mathrm{TeV})^2$

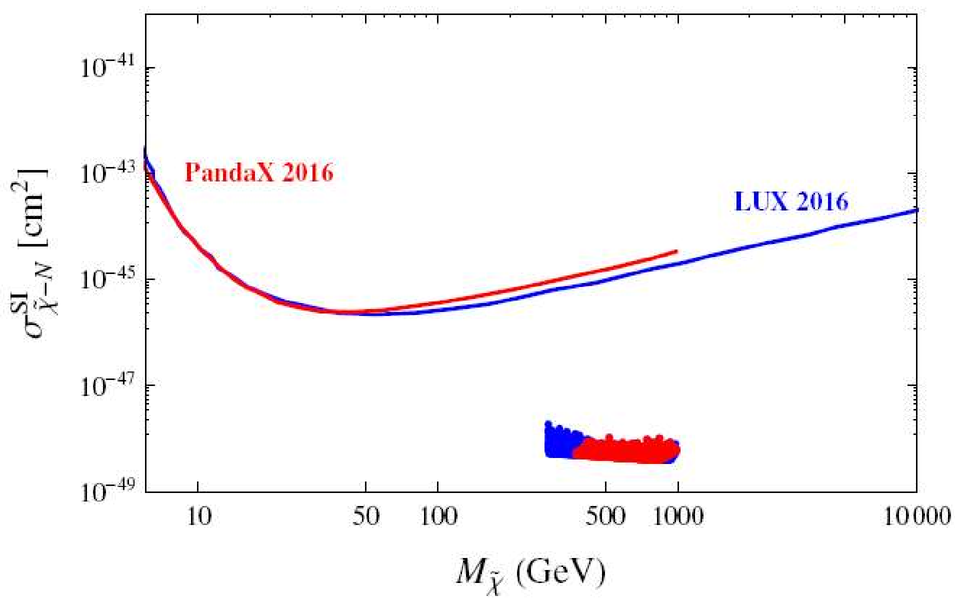
● axion superfield $A = \frac{1}{\sqrt{2}}(s + ia) + \sqrt{2}\theta\tilde{a} + \theta^2 F$

K. J. Bae, H. Baer, A. Lessa and H. Serce, JCAP 1410, no. 10, 082 (2014)

H. Baer, K. Y. Choi, J. E. Kim and L. Roszkowski, Phys. Rept. 555, 1 (2015)

K. J. Bae, H. Baer, A. Lessa and H. Serce, Front. in Phys. 3, 49 (2015)



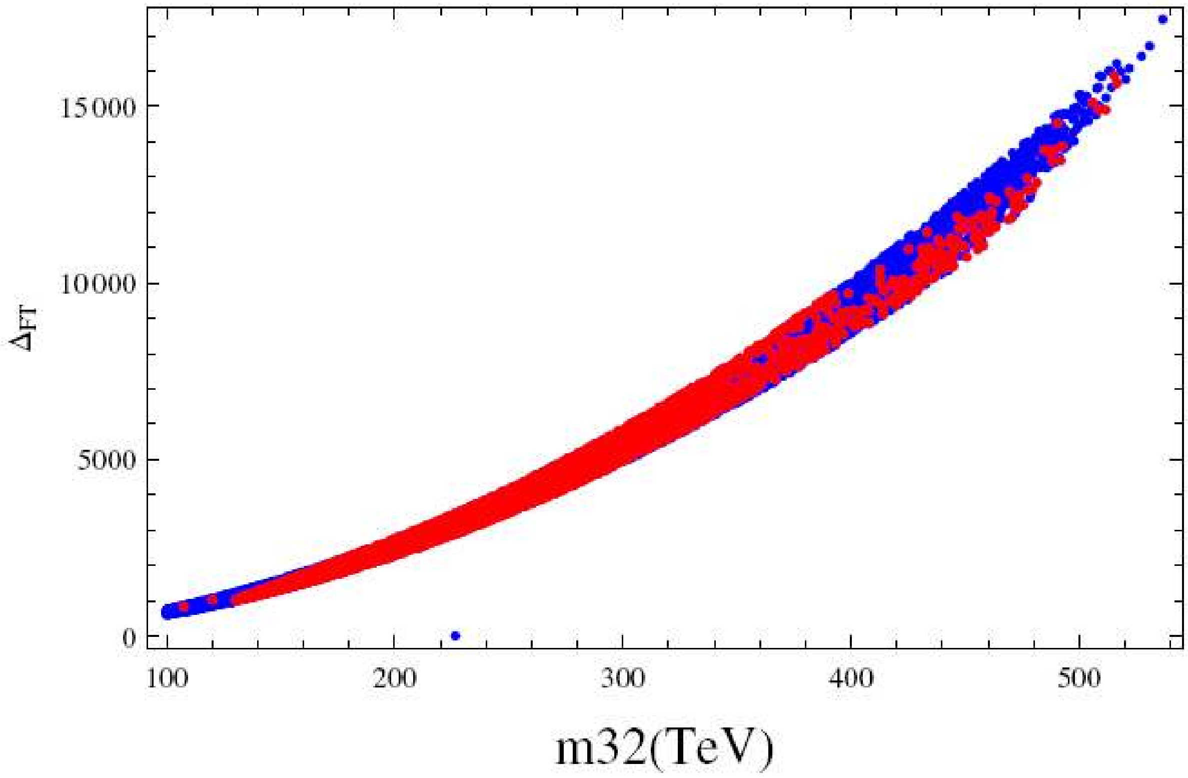


Fine-tuning measure

Barbieri-Giudice netuning measure

R. Barbieri and G. F. Giudice, Nucl. Phys. B 306, 63 (1988)

$$\Delta_{\rm FT} = {\rm Max}\{\Delta_\alpha\}\,,\ \Delta_\alpha = \frac{\partial \ln M_Z^2}{\partial \alpha}$$



谢谢大家