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Semi-natural Gauge Mediation from Product Group Unification

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with

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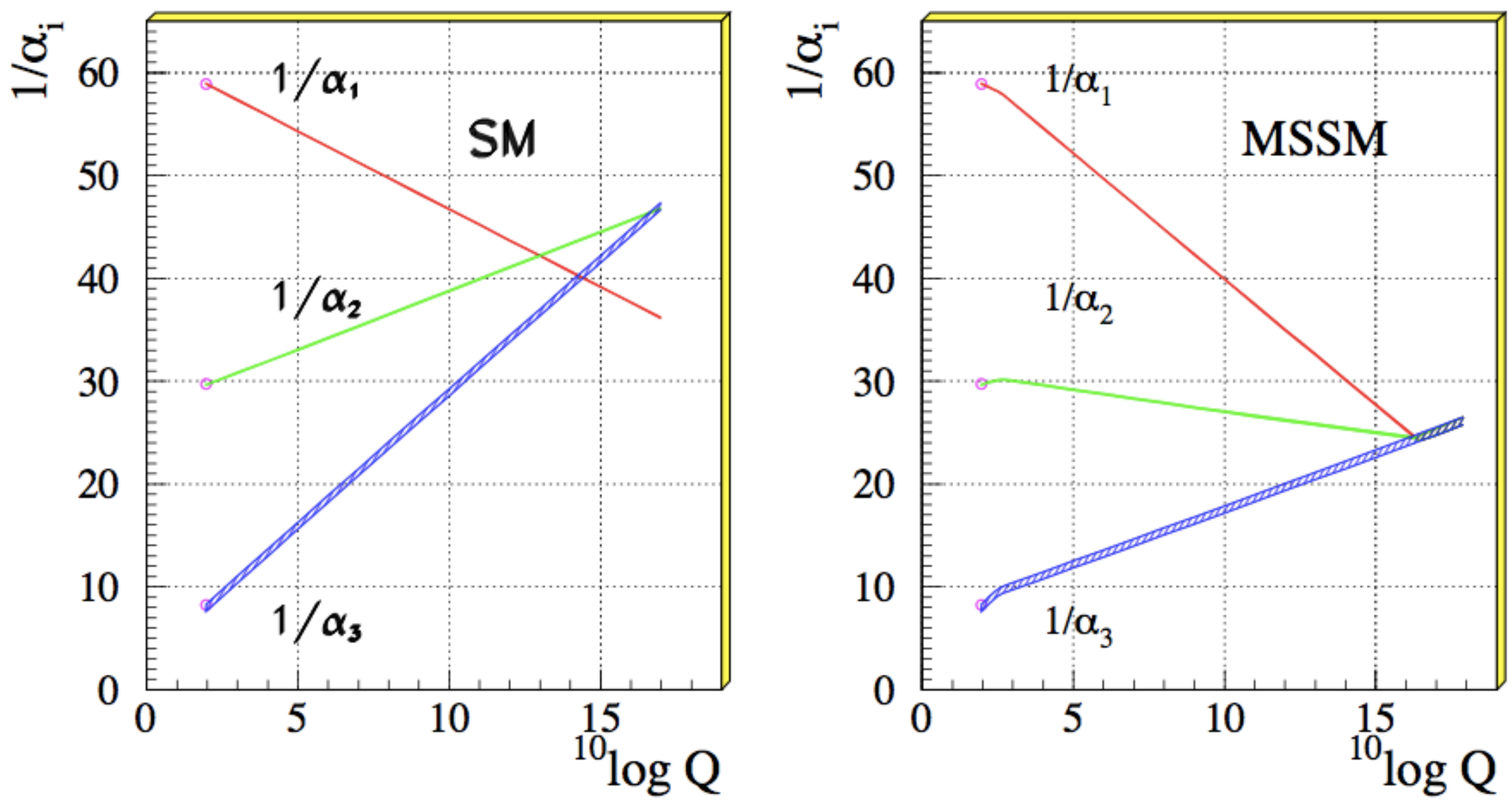
PRD, arXiv:1508.00445

Supersymmetric SM

- Gauge couplings unify around 10^{16} GeV.



[hep-ph/0012288]

- Stabilizing the large hierarchy between the Planck/GUT/PQ breaking scale and the EWSB scale

- **The EWSB scale is possibly understood from the SUSY particle mass scale**

- Negative quadratic term in the Higgs potential is induced from loops involving top-squark and gluino, **thanks to Yt~1**.

EWSB condition:

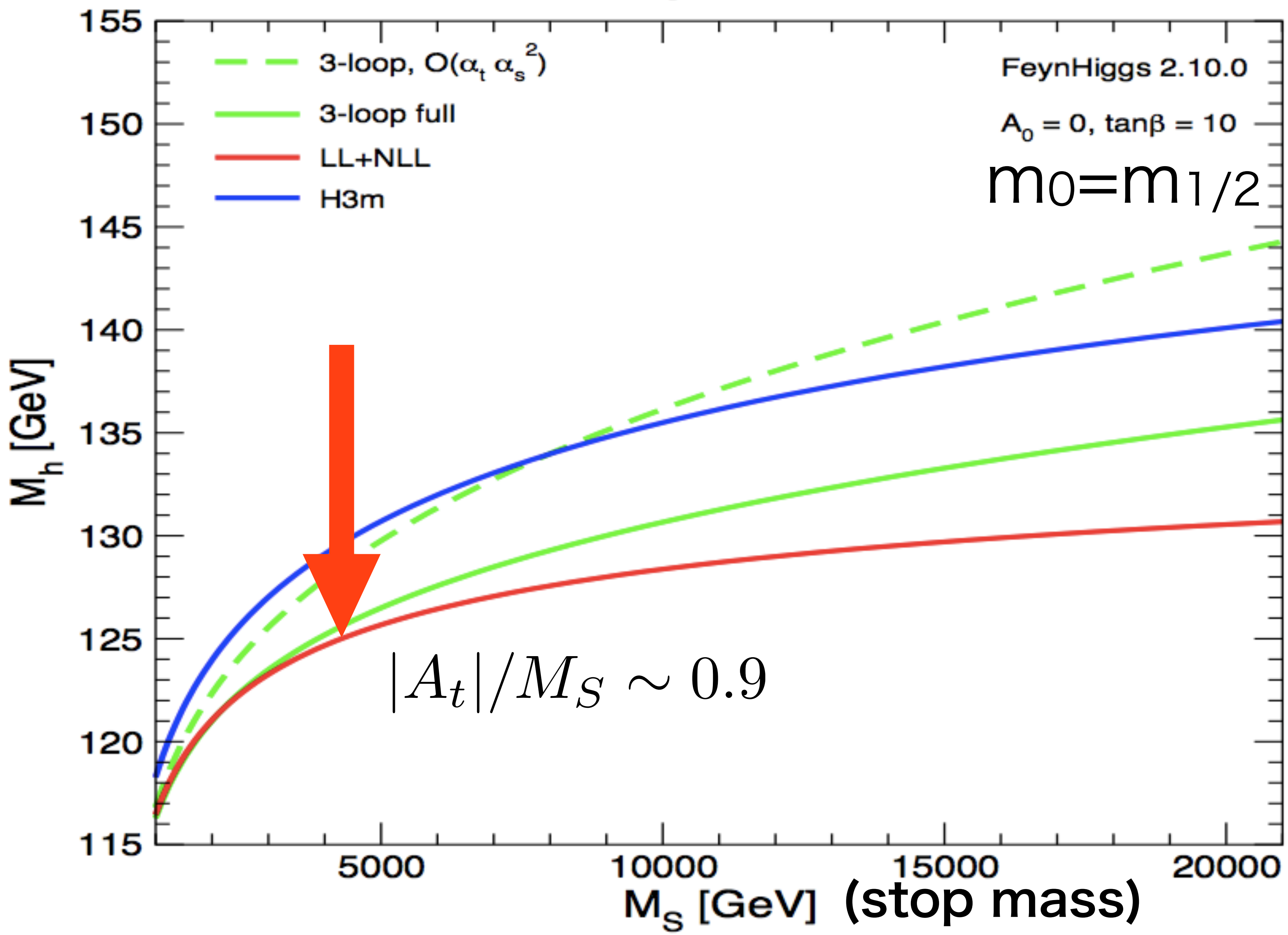
$$m_Z^2 \simeq -2\left[m_{H_u}^2 + \mu^2 + \frac{1}{2v_u}\frac{\partial \Delta V_{CW}}{\partial v_u}\right] + \mathcal{O}(1/\tan^2\beta) + \ldots$$

($\tan\beta = v_u/v_d$ is determined by the other EWSB condition)

- The size of negative m_{Hu}^2 is around the stop mass
  → the natural size of m_Z is the stop mass
  → **If the stop mass ~ m_Z, the EWSB is explained by the SUSY breaking mass scale**.

- However, the LHC excludes,
  top-squark (stop) < 600 GeV, gluino < 1.4 TeV

- **The observed Higgs boson mass of 125 GeV requires, stop > 3-5 TeV**



[T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak, G. Weiglein, 2013]

Approaches to the origin of the EWSB scale

- The best way is to consider the SUSY mass scale as well as the mediation scale is low, **though difficult**.
- Never mind (just a little hierarchy)

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Focus point!

- **Special relation(s) among parameters at UV physics, reducing the fine-tuning.**

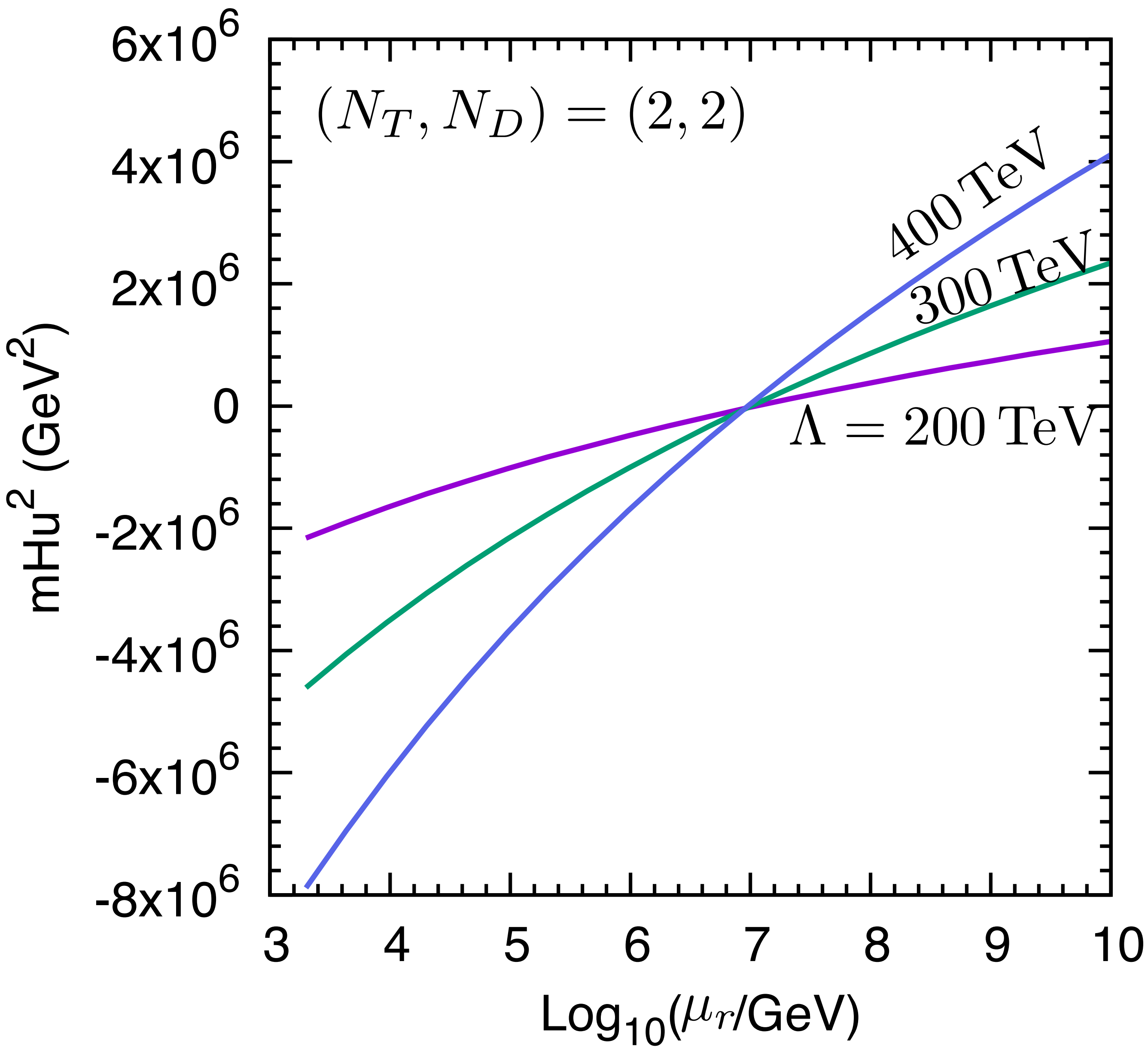
Focus point gauge mediation

- The masses of the SUSY particles are generated from **loops from messengers, which are charged under the SM gauge group.**
- **The absence of the FCNC processes** is guaranteed.
- If numbers of SU(2) doublet messengers and SU(3) doublet messengers are **$(N_D, N_T)=(5, 2)$**, **the expected EWSB scale becomes much smaller than the stop mass scale.**

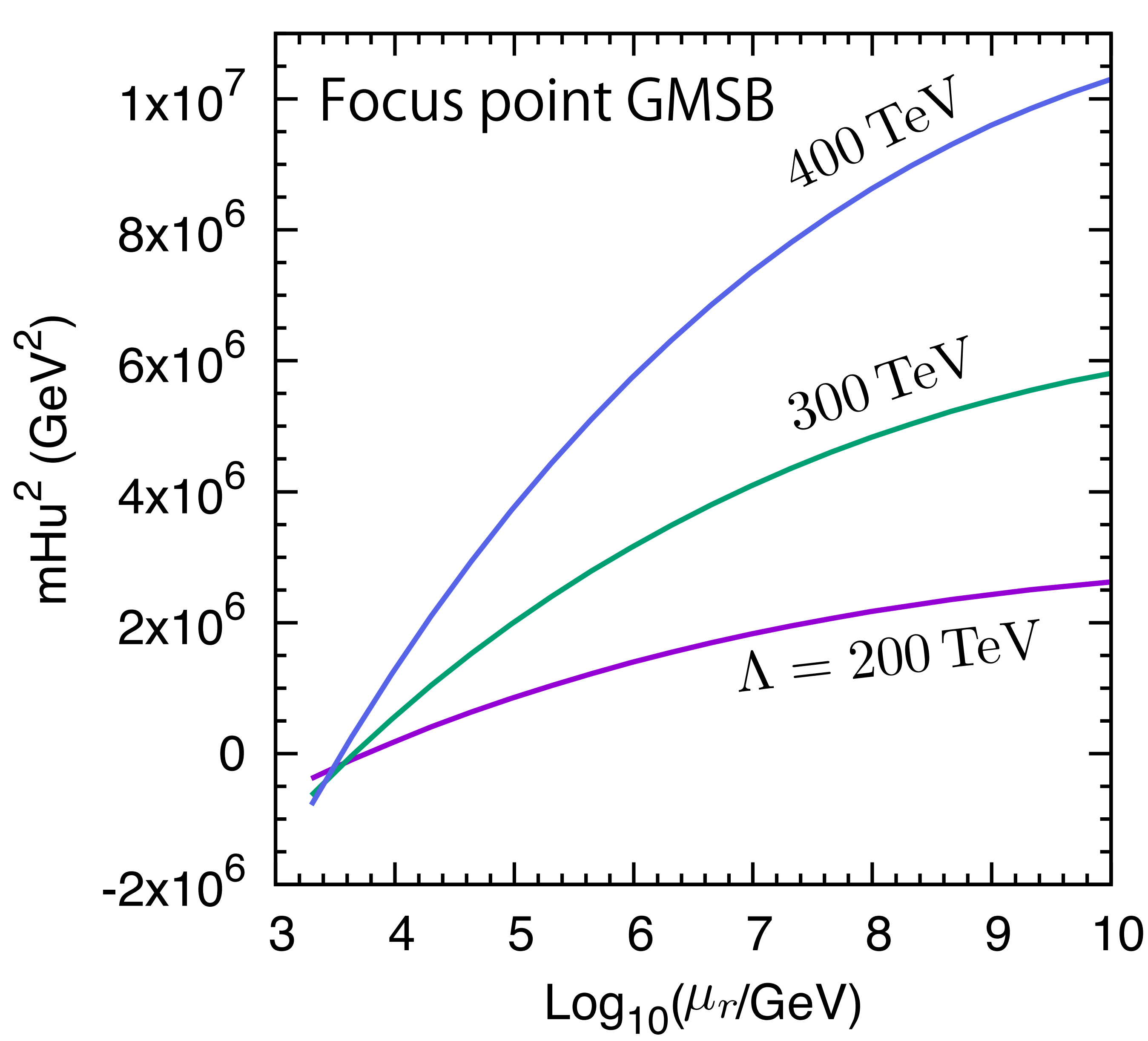
$$\bar{\mathbf{5}} = (\bar{\mathbf{3}}, \mathbf{1})_{1/3} + (\mathbf{1}, \mathbf{2})_{-1/2}$$

x 2 x 5

Running of mHu^2



minimal GMSB



focus point GMSB

[see also, Brummer and Buchmuller, 2012; Brummer, Ibe and Yanagida, 2013]

Good things

- The focus point behavior is controlled by the messenger numbers. (not continuous valuables)
- The behavior is stable against radiative correction.

Bad things

- No reason for $(N_D, N_T)=(5, 2)$, i.e. $N_D=N_T$ is natural
- **GUT is messy if one consider e.g. SU(5)!**

- $N_D/N_T=5/2$ is naturally explained in the product group unification model, **based on $SU(5)\times U(3)_H$**
- Why do we need the product group unification?

The product group unification provides a simple way to solve the doublet-triplet splitting problem

10^{-14}-10^{-15} tuning

$SU(5) \times U(3)_H$ product group unification

- The DT-splitting (DTS) is easily achieved
- **Gauge coupling unification** is still hold approximately if the coupling of $U(3)_H$ is strong
- **Charge quantization** of the MSSM particles is hold

[Hotta, Izawa, Yanagida, 1995; Watari, Yanagida, 2002]

- SU(5)xU(3)$_H$ is broken to the SM gauge group, by the VEVs of bi-fundamental fields

$$B = (\mathbf{5}, \bar{\mathbf{3}}) \qquad \bar{B} = (\bar{\mathbf{5}}, \mathbf{3})$$

$$\langle B^i_\alpha \rangle = v_{\rm GUT} \delta^i_\alpha \qquad \langle \bar{B}^\alpha_i \rangle = v_{\rm GUT} \delta^\alpha_i$$

i=1..5

α=1..3

Then, $$W = H^i \bar{B}^\alpha_i \bar{T}_\alpha + \bar{H}_i B^i_\alpha T^\alpha$$

$$\Downarrow$$

$$v_{GUT} H_C \bar{T} + v_{GUT} \bar{H}_C T$$

Colored Higgs multiplets become heavy, while doublets remain massless.

(The doublet mass can arise from a symmetry breaking term.)

Adjoint messengers in $SU(5) \times U(3)_H$

- Let us consider the messenger field in the adjoint representation of SU(5), **24**

$SU(3) \times SU(2) \times U(1)_Y$:

(**8**, **1**, 0) → $\Delta b_2 = 0$, $\Delta b_3 = 3$

(8,1,0) becomes heavy with a similar mechanism for DTS

(**1**, **3**, 0) → $\Delta b_2 = 2$, $\Delta b_3 = 0$

(**3**, **2**, -5/6)
(**3***, **2**, 5/6) → $\Delta b_2 = 3$, $\Delta b_3 = 2$

→ $(\Delta b_2)_{total} = 5$, $(\Delta b_3)_{total} = 2$

corresponding to $(N_D, N_T) = (5,2)$

Estimation of the fine-tuning

- Finally, we estimate the fine-tuning using the following measure:

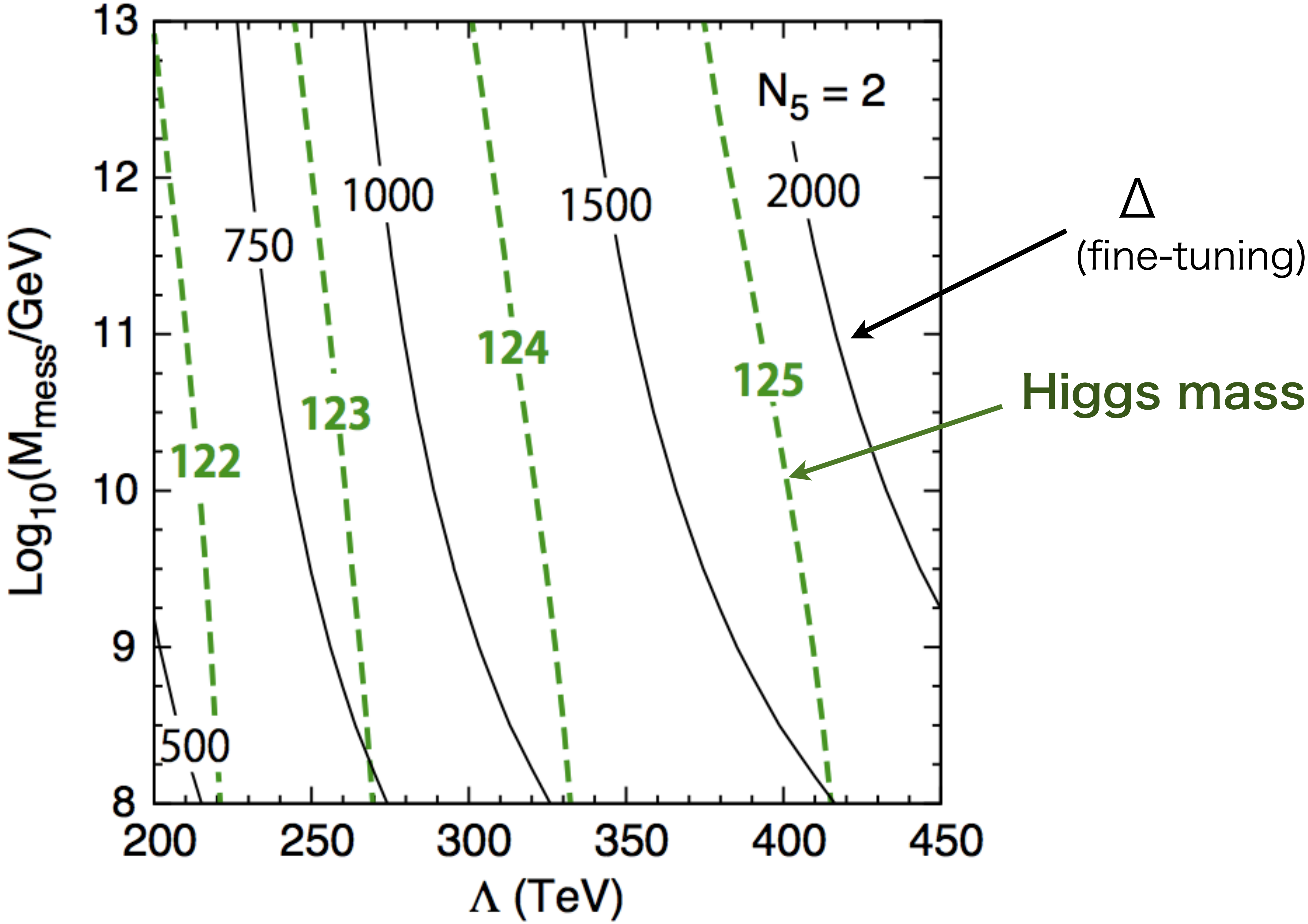
$$\Delta = \max\{\Delta_a\}, \quad \Delta_a = \left\{ \frac{\partial \ln m_{\hat{Z}}}{\partial \ln |\mu|}, \frac{\partial \ln m_{\hat{Z}}}{\partial \ln |F_Z|}, \frac{\partial \ln m_{\hat{Z}}}{\partial \ln |B_{\rm mess}|} \right\}_{m_{\hat{Z}} = 91.2 \mathrm{GeV}}$$

[Barbieri and Giudice, 1988]

We regard F_Z, μ and B_{mess} as independent fundamental parameters

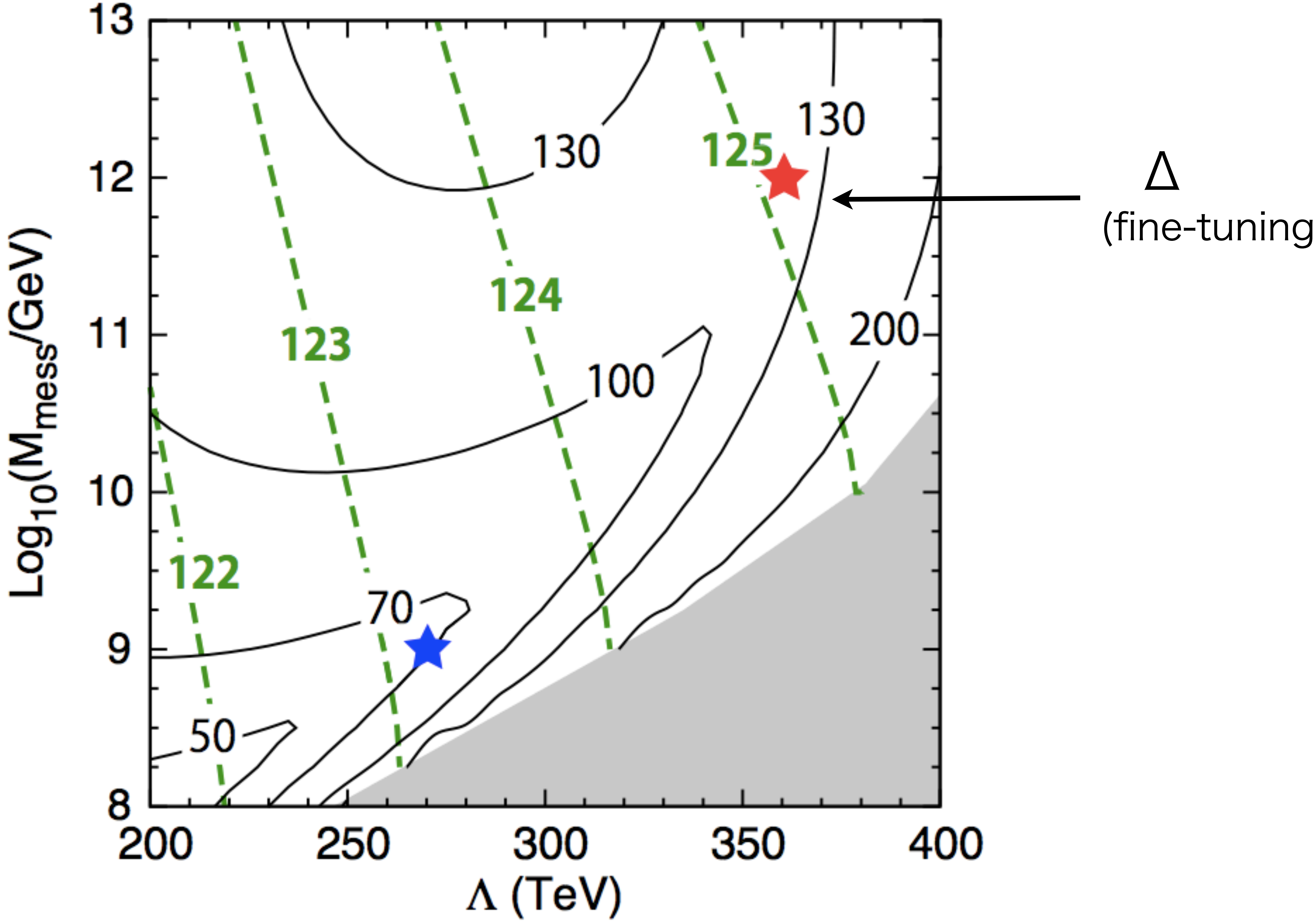
Minimal GMSB with 5 5* messengers

($N_T=N_D=2$) (very ordinary case)



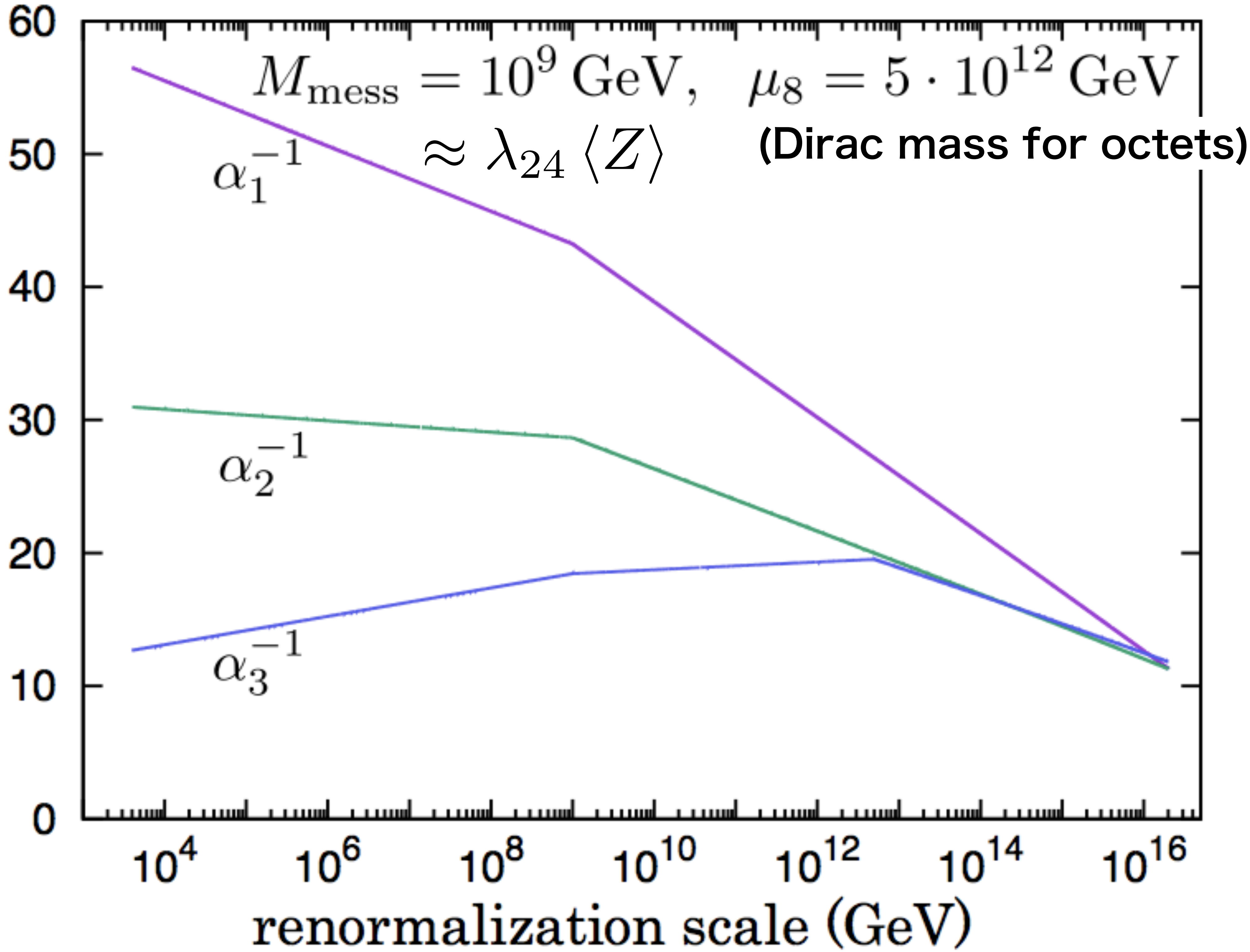
$\tan\beta = 25$, $m_t(\text{pole}) = 173.34\,\text{GeV}$ and $\alpha_s(m_Z) = 0.1185$.

Focus point gauge mediation



There exist solutions with B_{mess}=0 for μ<0 and tanb~25-30, where the SUSY CP-problem is solved.

The gauge couplings unify consistently



(2-loop RGEs are used)

Summary

- There still exist a hope to understand the origin of the EWSB scale **if the UV physics provides certain relation(s)** among soft SUSY breaking masses.
- The **semi-natural SUSY** may be as **a result of the product group unification**, which is somewhat natural from the view point of the doublet-triplet splitting.
- The SUSY CP-problem can be also solved.
- To be completed, we need to explain **why the EWSB is sensitive to the top Yukawa coupling**.

Consistency with gravitino cosmology (briefly)

- The thermalized **gravitino can be dark matter without over-closure of the universe**.
- This is achieved with **a late-time entropy production** from the decay of the messenger, diluting the gravitino abundance.
- Baryon number is explained via **the thermal Leptogenesis** with $M_N = 10^{(11\text{-}12)}$ GeV and $T_R > M_N$.
  (M_N is a RH neutrino mass, T_R is a Reheating temperature)