Top partners, fermion mass matrices and Higgs boson production

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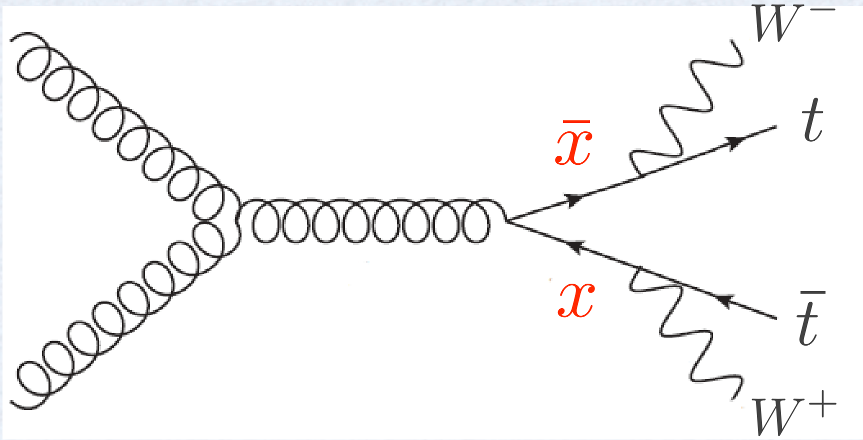
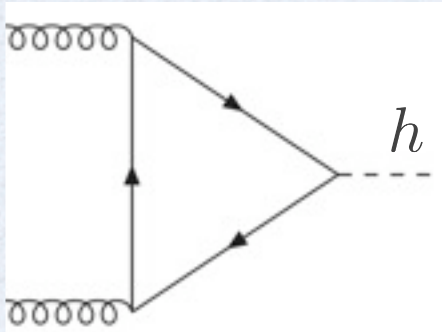
Motivation

- experiments point towards a relatively light Higgs boson
- *"a light fundamental scalar is not natural"*: the hierarchy problem
- many extensions of the Standard Model introduce new particles that can alter the LHC phenomenology



direct production

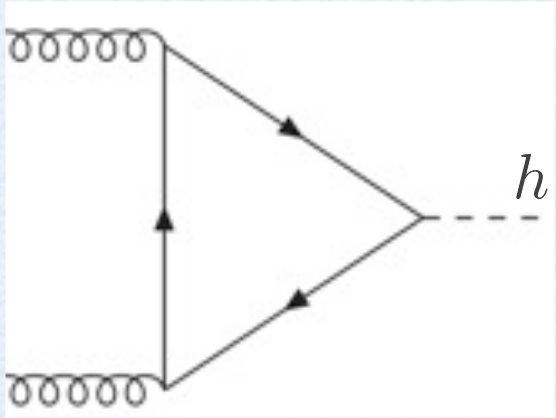
loop effects

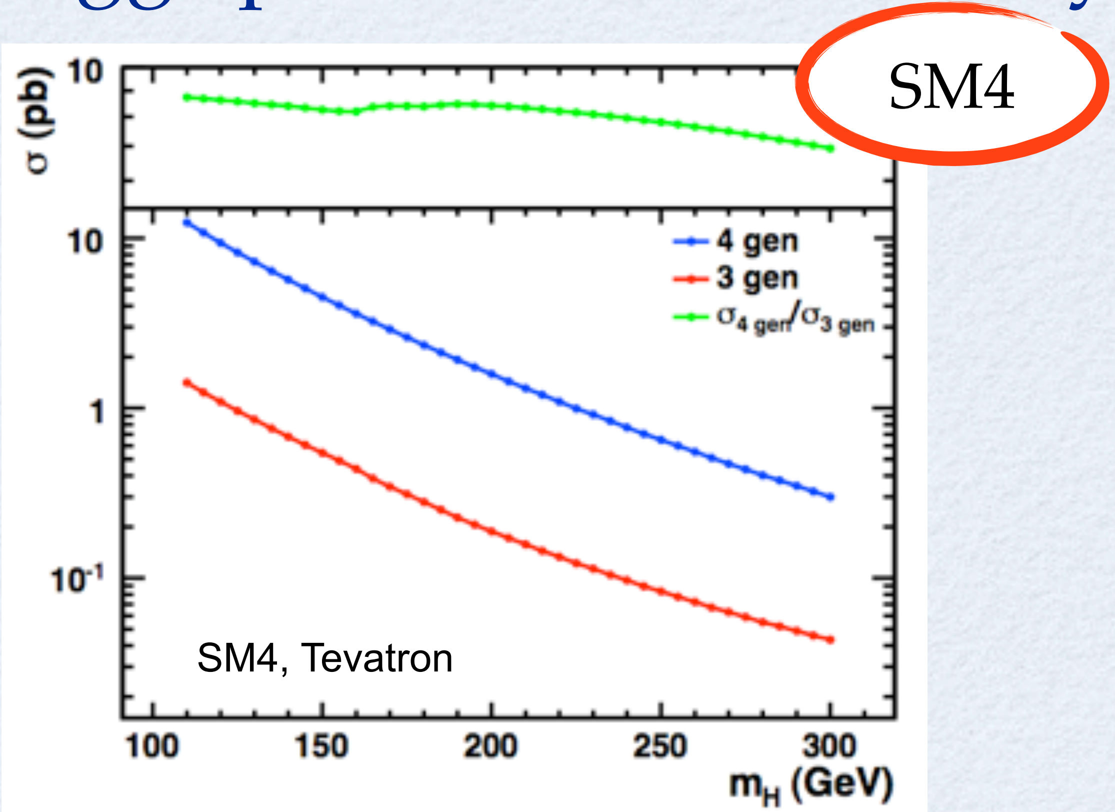


MOTIVATION

- the new particles typically
  - couple to the Higgs boson
  - mix with the Standard Model top quark, modifying its coupling to the Higgs boson

➡ *can* significantly affect Higgs production and decays





MOTIVATION

- the new particles typically
  - couple to the Higgs boson
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➡ *can* significantly affect Higgs production and decays

➡ but.. do they *have to*?

Vector-like singlet

- they are introduced for example in little Higgs and composite Higgs models

- the fermion mass terms are

$$-\mathcal{L}^{(s)} = \underbrace{\alpha \bar{q}_L H d_R + a \bar{q}_L \tilde{H} u_R}_{-\mathcal{L}^{SM}} + \underbrace{b \bar{q}_L \tilde{H} U_R + c \bar{U}_L u_R + d \bar{U}_L U_R}_{\text{mixing terms}} + \text{h.c.}$$

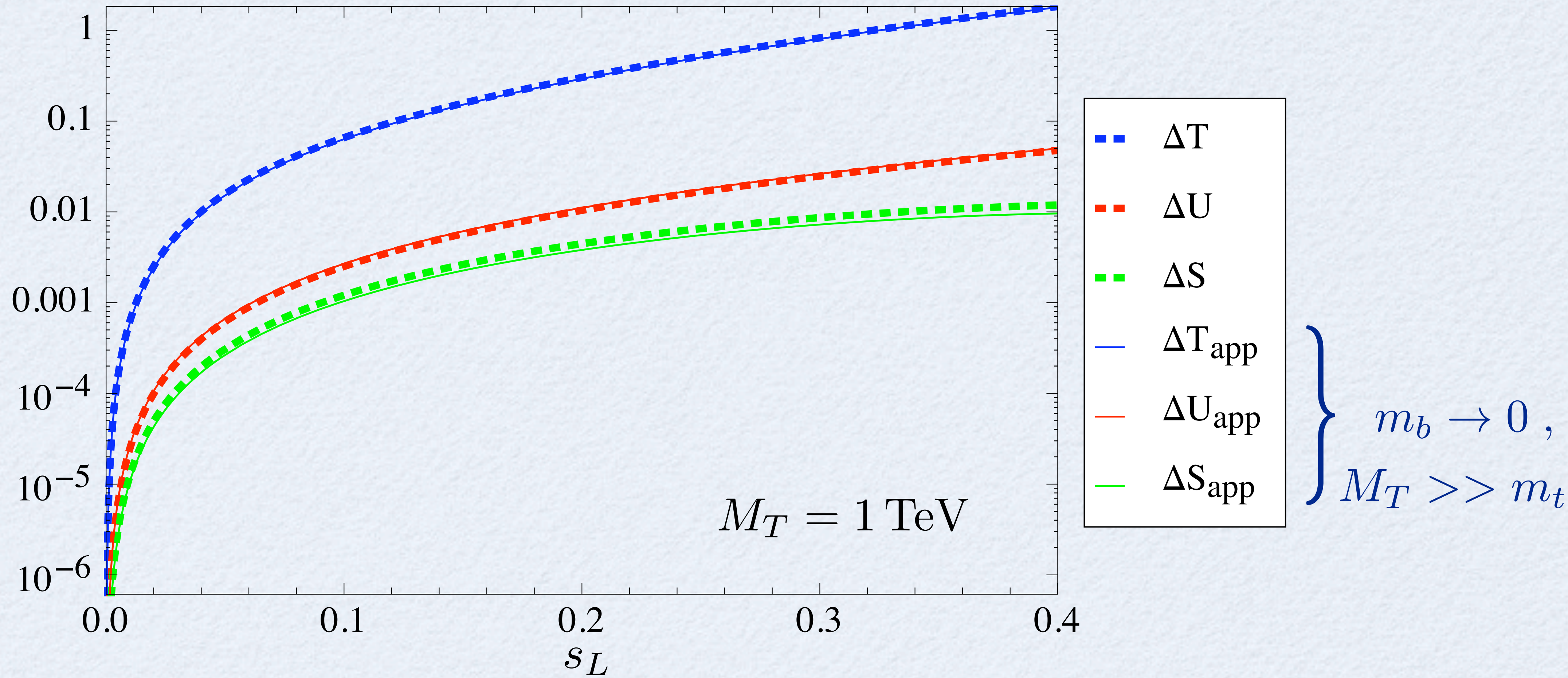
➡ the charge 2/3 mass eigenstates t, T are an admixture of u and U

$$\begin{pmatrix} t_i \\ T_i \end{pmatrix} = \begin{pmatrix} c_i & -s_i \\ s_i & c_i \end{pmatrix} \begin{pmatrix} u_i \\ U_i \end{pmatrix}$$

$$c_i = \cos(\theta_i) \; , \quad s_i = \sin(\theta_i) \quad i = L, R$$

Constraints: S, T, U

- Contribution to the Peskin - Takeuchi S, T, U parameters:

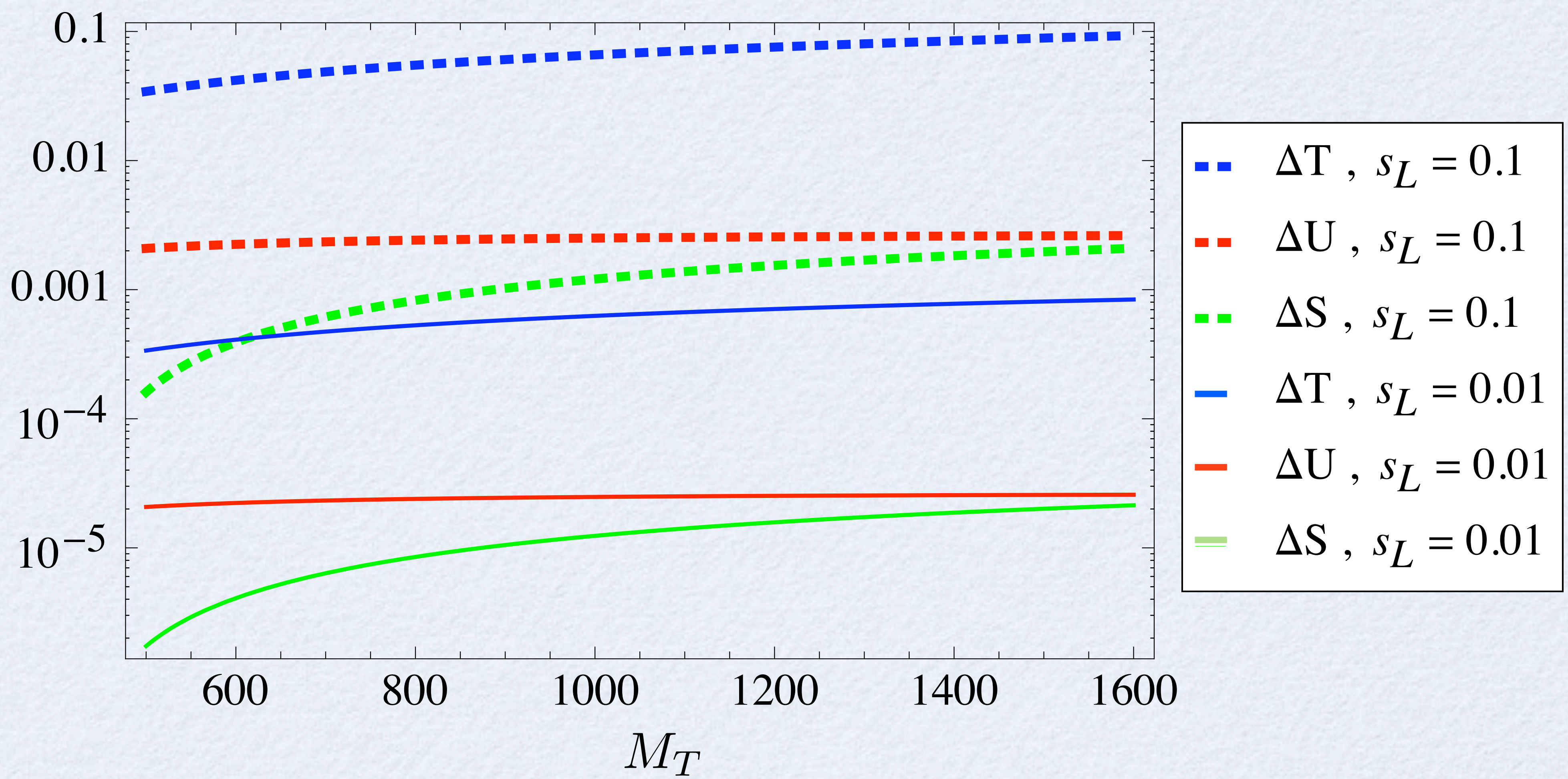


$$\Delta T_{app} = T_{SM} s_L^2 (r s_L^2 + 2c_L^2 \log r - 1 - c_L^2) \qquad r = (M_T/m_t)^2$$

$$\Delta S_{app} = -\frac{N_c}{18\pi} s_L^2 [\log r\,(1 - 3c_L^2) + 5c_L^2] \quad , \quad \Delta U_{app} = \frac{N_c}{18\pi} s_L^2 (3s_L^2 \log r + 5c_L^2)$$

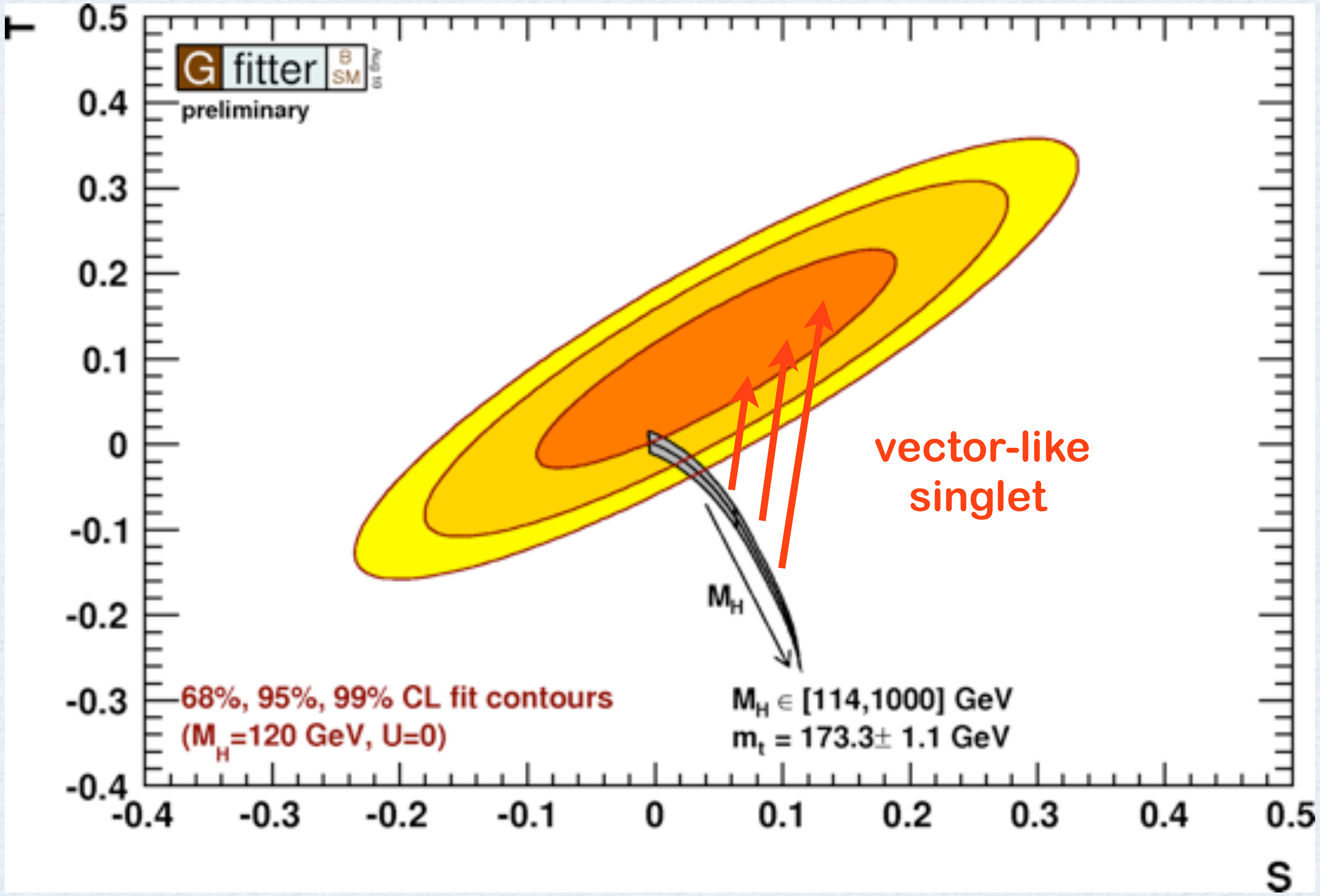
Constraints: S, T, U

- Contribution to the Peskin - Takeuchi S, T, U parameters:



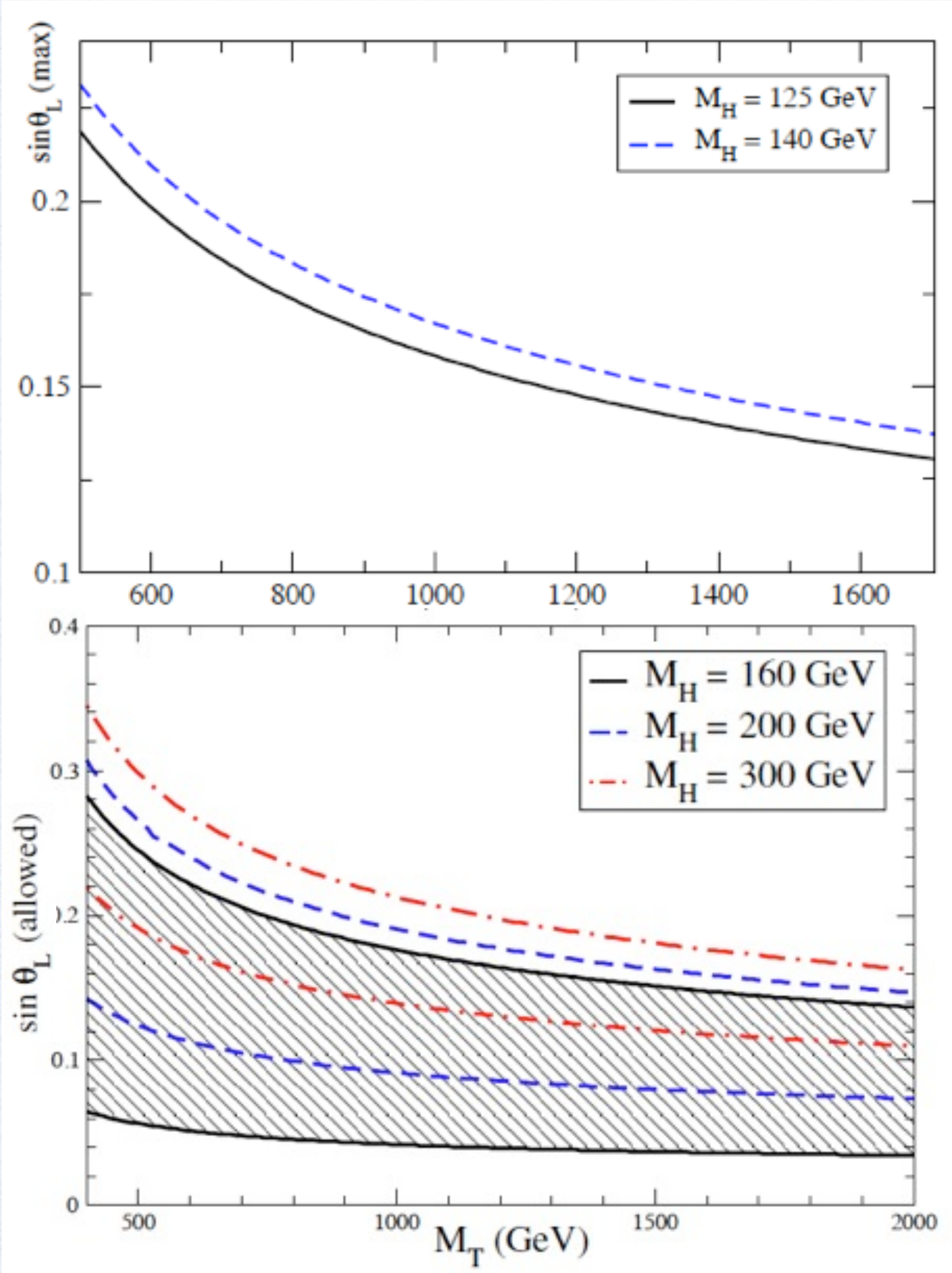
Constraints: S, T, U

- Note that both ΔT , $\Delta S > 0$, but $\Delta T >> \Delta S \Rightarrow$



Constraints: S, T, U

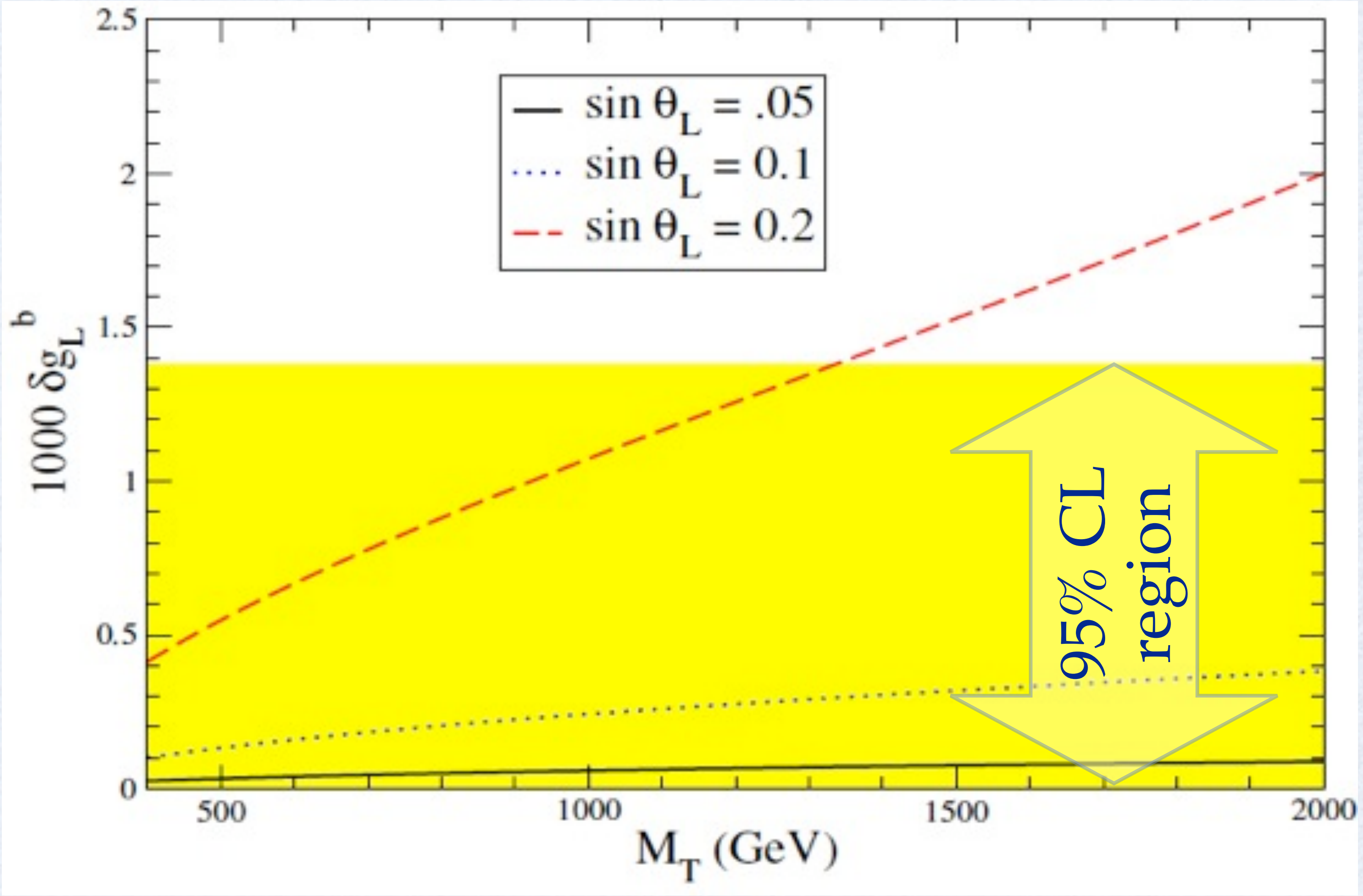
95% CL Regions
allowed
by S, T, U



Constraints: $Z \to b_L \bar{b}_L$

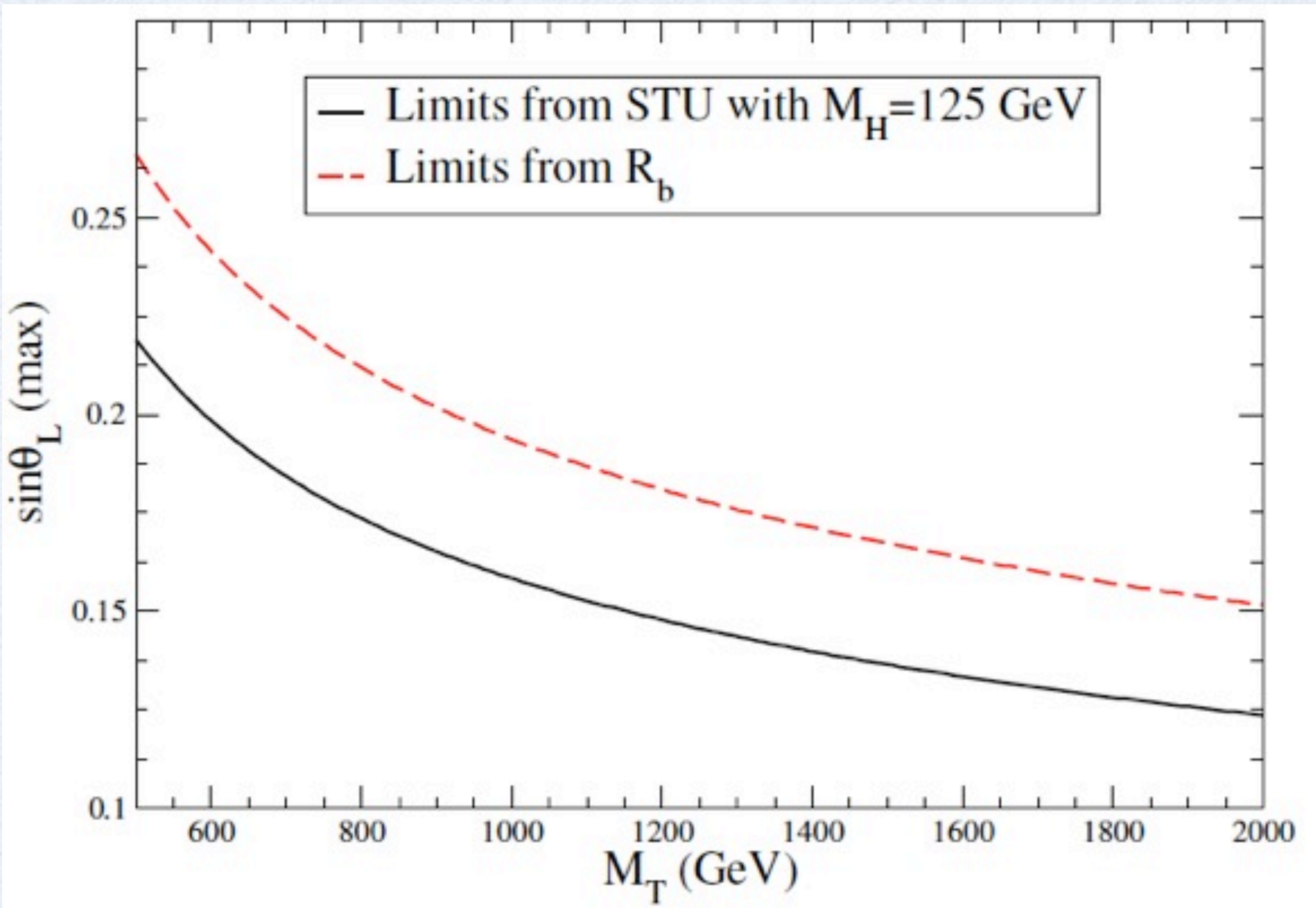
- In the approximation m_t , $M_T >> M_W$,

$$\delta g_b^L = \frac{G_F}{\sqrt{2}} \frac{1}{8\pi} m_t^2 s_L^2 \left(s_L^2 r - c_L^2 - 1 + 2 c_L^2 \frac{r}{r-1} \log r \right)$$



Combined constraints

- In the singlet model, the strongest constraints come from the oblique parameters



DECOUPLING

$$-\mathcal{L}^{(s)} = a\bar{q}_L\tilde{H}u_R + b\,\bar{q}_L\tilde{H}U_R + c\,\bar{U}_Lu_R + d\,\bar{U}_LU_R$$

- decoupling occurs for

$$c, d >> \frac{av}{\sqrt{2}}, \frac{bv}{\sqrt{2}} \text{ and } d >> c$$

- in this limit

$$M_T \sim d\,, \quad m_t \sim av/\sqrt{2}\,, \quad s_L \sim v/M_T$$

➡

$$\Delta T \sim T_{SM}\, s_L^2 \left(r s_L^2 - 2 + 2\log r \right) \to 0\,, \qquad r = (M_T/m_t)^2$$

$$\Delta S \sim -\frac{N_c}{18\pi} s_L^2 \left(5 - 2\log r\right) \to 0\,,$$

$$\Delta U \sim \frac{N_c}{18\pi} s_L^2 5 \to 0\,,$$

$$\delta g_b^L \sim \frac{G_F}{\sqrt{2}} \frac{m_t^2}{8\,\pi^2} s_L^2 \left(s_L^2 r + 2c_L^2 \frac{r}{r-1} \log r \right) \to 0\,.$$

Higgs Production

- mixing with the singlet reduces the coupling of the top-like quark to the Higgs and yields a coupling to the Higgs also for the heavy top partner

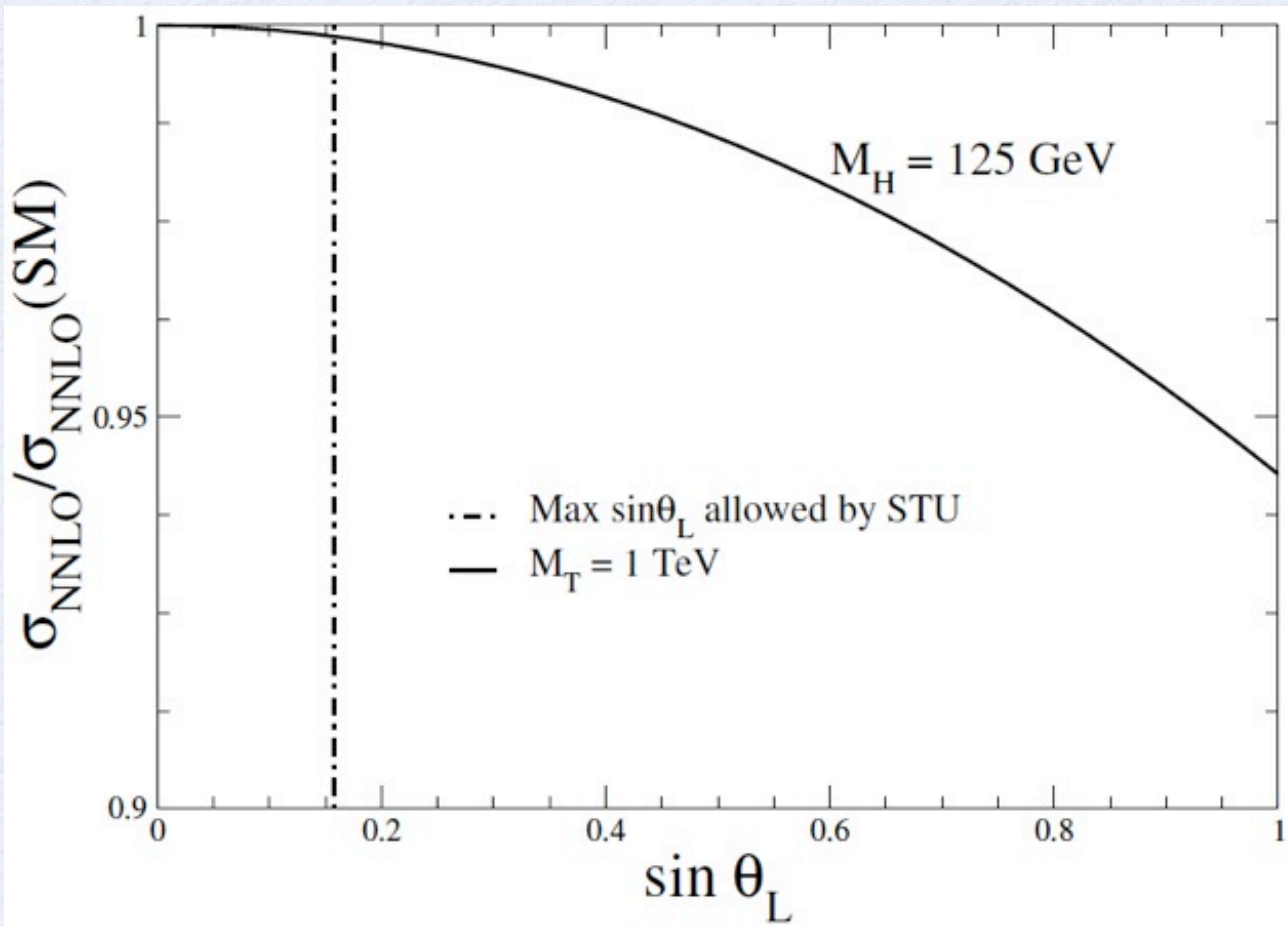
$$Y_t = c_L^2 \frac{m_t}{v} \quad , \; Y_T = s_L^2 \frac{M_T}{v}$$

- the Higgs production cross section is suppressed with respect to the Standard Model

$$\left.\frac{\sigma^{(s)}}{\sigma^{SM}}\right|_{LO} \approx 1 - \frac{7}{15} \frac{m_H^2}{4 m_t^2} s_L^2 \left(1 - \frac{m_t^2}{M_T^2}\right) \xrightarrow{\text{decoupling}} 1$$

HIGGS PRODUCTION

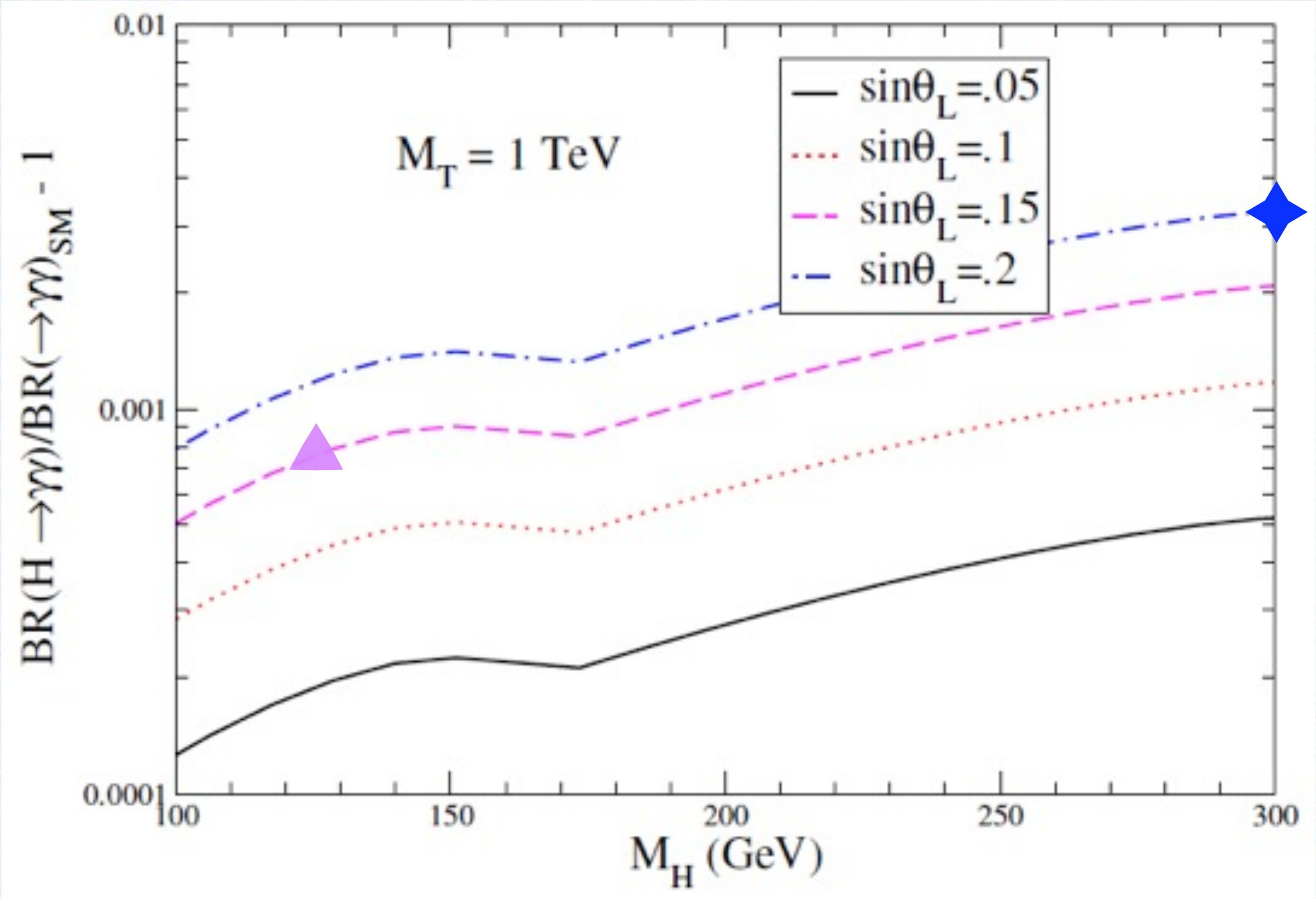
- potentially large effect, but electroweak observables require a small mixing angle ⇨ at most some few % effect



generated with **ihixs**
Anastasiou et al., **JHEP 1112 (2011) 058**
EF, **JHEP 1110 (2011) 115**

Higgs decays

- the new top-partner also affects loop-mediated Higgs decays
- only small mixing angles allowed ⇨ below %-level effects



CONCLUSIONS

Vector-like singlet

- the strongest constraints on the parameter space come from the Peskin-Takeuchi parameters
- yields a positive contribution both to S and T, but

$$\Delta T >> \Delta S$$

  - ➡ improve the electroweak fit for an heavy Higgs
- decouples for $M_T \to \infty$, $s_L \sim v M_T^{-1}$
- reduces the Higgs production cross section
  - ➡ the fit to electroweak precision observables forces this reduction to small
  - ➡ Higgs production and decays will look the same as in the Standard Model