A rather unusual supersymmetry,
paying attention to the flavour problem as well

A bottom-up viewpoint

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in progress with Bertuzzo, Farina, Lodone, Pappadopulo

1. Motivations: a matter of naturalness, once again

MSSM: $m_h \lesssim m_Z |\cos 2\beta|$ + rad. corr.

$$\frac{m_{\tilde{t}^2}}{m_h^2}\frac{\delta m_h^2}{\delta m_{\tilde{t}^2}}$$

$\Leftrightarrow$ a limit on $m_{\tilde{t}}$

hence the Higgs mass problem

$$\frac{m^2_{\tilde{q}_{1,2}}}{m_h^2}\frac{\delta m_h^2}{\delta m^2_{\tilde{q}_{1,2}}}$$

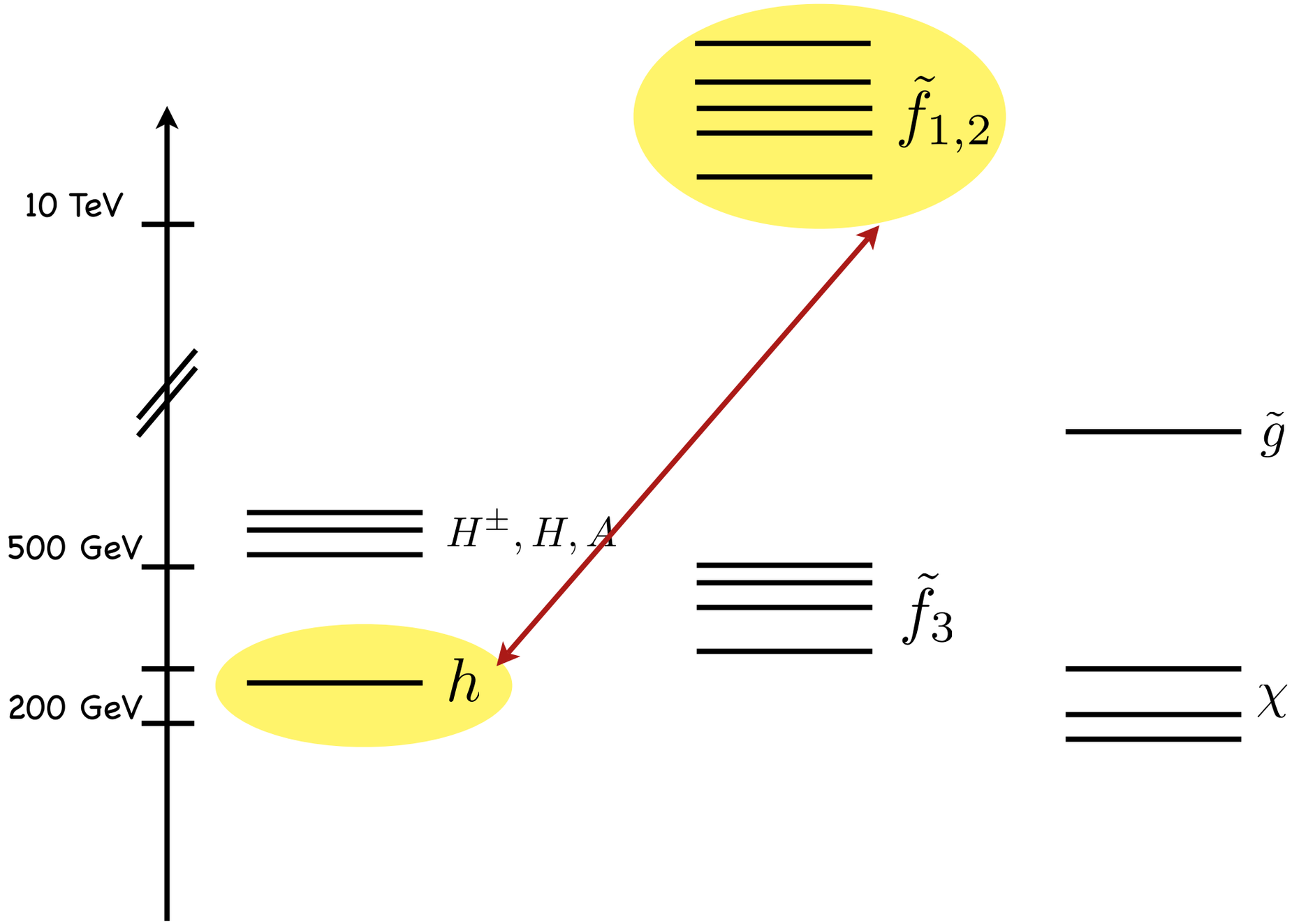
?

$\Leftrightarrow$ the flavour problem

Related problems?

Enough to try to go beyond the MSSM?

A Non Standard Supersymmetric Spectrum



Can it be naturally implemented?

2. Hierarchical s-fermion masses and flavour physics: a summary

1. No degeneracy, nor alignment

Dine, Kagan, Samuel
Pomarol, Tommasini
Cohen, Kaplan, Nelson

Giudice, Nardecchia, Romanino

Real ΔS=2 $\quad m_{\tilde{q}_{1,2}} \gtrsim 35\ TeV$

Im ΔS=2, max ϕ_{CP} $\quad m_{\tilde{q}_{1,2}} \gtrsim 800\ TeV$

2. Assume $\delta_{12}^{LL} \approx \frac{|m_1^2 - m_2^2|}{(m_1^2 + m_2^2)/2} \approx \lambda = 0.22$ and $\delta^{LL} \gtrsim \delta^{RR} >> \delta^{LR}$

ΔC=2 $\quad m_{\tilde{q}_{1,2}} \gtrsim 3\ TeV$

Im ΔS=2, $\sin\phi_{CP} \approx 0.3$ $\quad m_{\tilde{q}_{1,2}} \gtrsim 12\ TeV$

3. Assume a correlation $\delta_{i3}^{LL} \approx \frac{m_{\tilde{q}_3}^2}{m_{\tilde{q}_i}^2};\ i = 1,2$

ΔB=2 $\quad m_{\tilde{q}_{1,2}} \gtrsim 6\ TeV(\frac{m_{\tilde{q}_3}}{500\ GeV})$

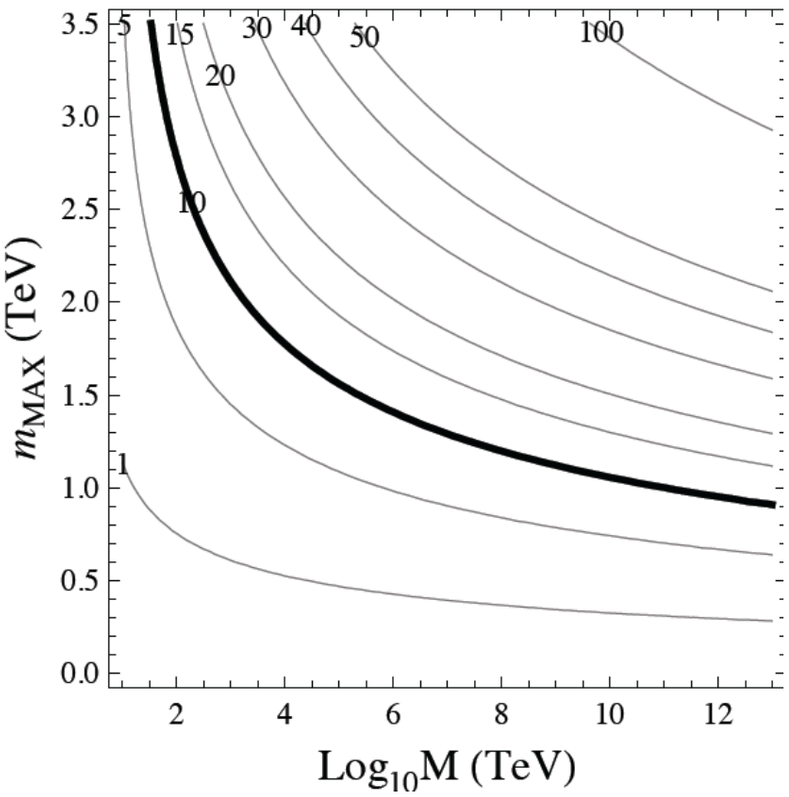
(EDM's give somewhat weaker constraints)

$\Rightarrow \quad m_{\tilde{f}_{1,2}} \gtrsim 10 \div 15\ TeV \qquad m_{\tilde{f}_3} \approx 500\ GeV$

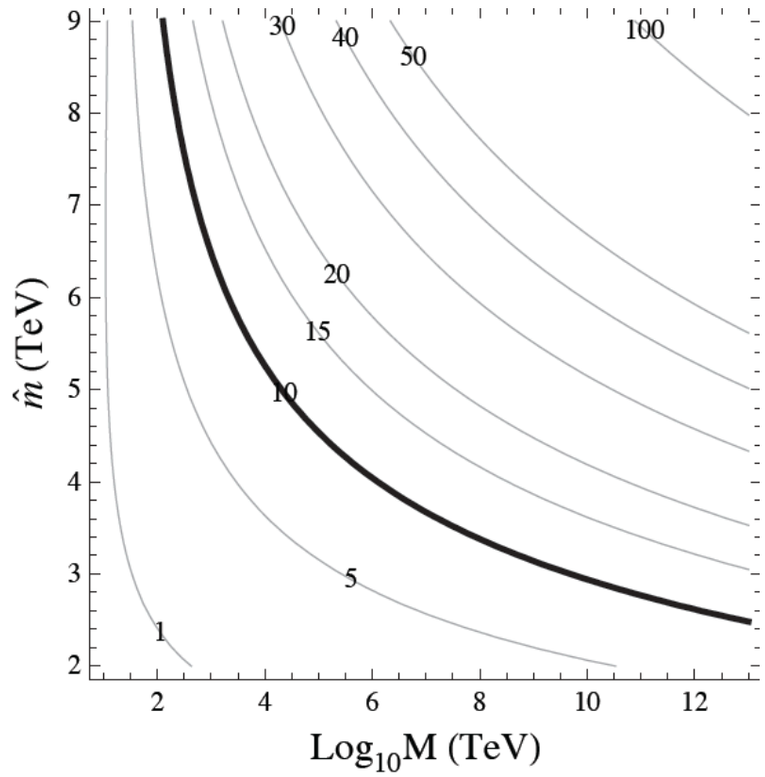
may be a way to solve the flavour problem

Bounds on $m_{\tilde{q}_{1,2}}$ from $\dfrac{m^2_{\tilde{q}_{1,2}}}{m_h^2}\dfrac{\delta m_h^2}{\delta m^2_{\tilde{q}_{1,2}}} < \Delta$

Dimopoulos, Giudice



with no particular condition at $M = M_{susy}$



with (partial) degeneracy among $\tilde{f}$'s of 1st and 2nd generations at M

$$\times \approx \frac{m_h}{m_Z}$$

⇒ For $m_{\tilde{q}_{1,2}} \gtrsim 10 \div 15\ TeV$ best to have $\dfrac{m_h}{m_Z} \gtrsim 2 \div 3$
thus addressing the Higgs mass problem as well

or $\dfrac{m_{\tilde{t}^2}}{m_h^2}\dfrac{\delta m_h^2}{\delta m_{\tilde{t}^2}} < \Delta$

3. Supersymmetry without a light Higgs boson

Want to keep the success of the EWPT
⇒ Effective theories not enough

✶ Extra U(1)

$$m_h^2 \leq (m_Z^2 + \frac{g_x^2 v^2}{2(1+\frac{M_X^2}{2M_\phi^2})})\cos^2 2$$

Batra, Delgado, Kaplan, Tait

✶ Extra SU(2)

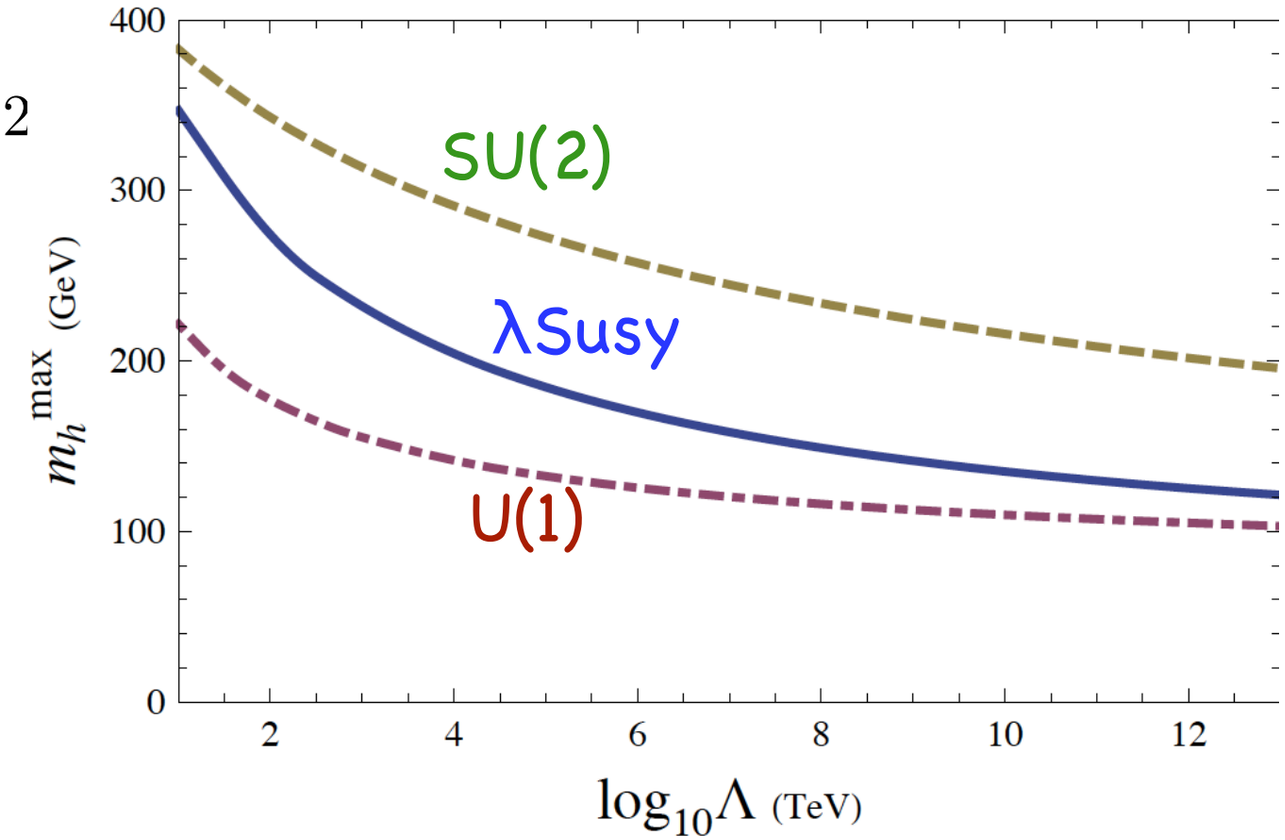
$$m_h^2 \leq m_Z^2 \frac{g'^2+\Delta g^2}{g'^2+g^2}\cos^2 2\beta$$

$$\Delta = \frac{1+\frac{M_\Sigma^2}{M_X^2}\frac{g_I^2}{g^2}}{1+\frac{M_\Sigma^2}{M_X^2}}$$

✶ $\Delta f = \lambda S H_1 H_2$

$$m_h^2 \leq m_Z^2(\cos^2 2\beta + \frac{2\lambda^2}{g^2+g'^2}\sin^2 2\beta)$$

Harnik, Kribs, Larson, Murayama
B, Hall, Nomura, Rychkov

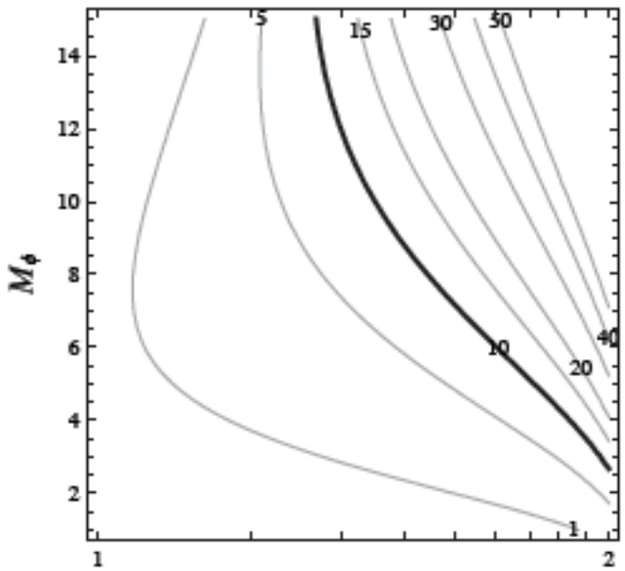


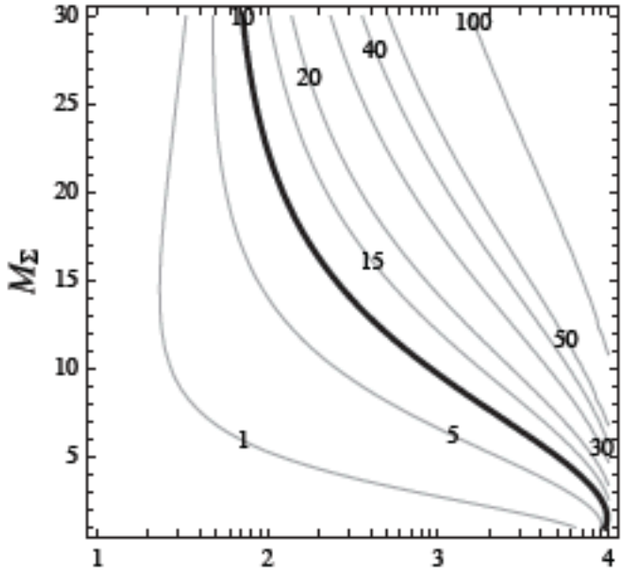
Λ is scale at which coupling gets semi-perturbative
(what happens above Λ not our concern, a bottom-up view)

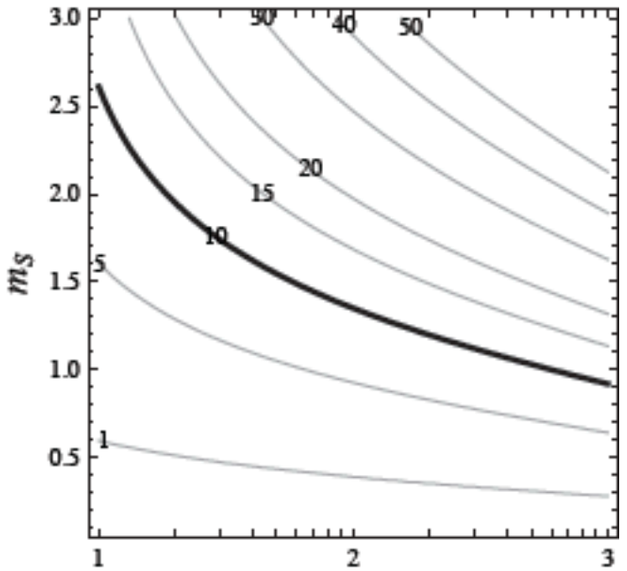
In gauge extensions $M_{\phi,\Sigma}/M_X$ maximized
consistently with naturalness oh higher vev

Naturalness bounds

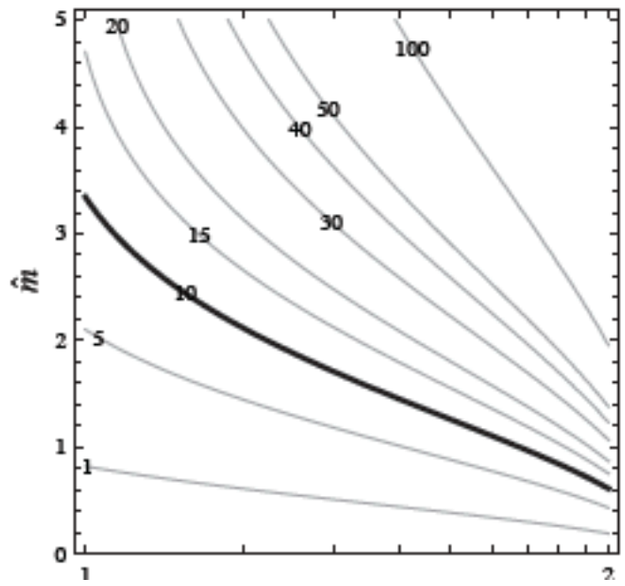
U(1) $m_h^{max} = 180\ GeV$ SU(2) $m_h^{max} = 250\ GeV$ λSusy $m_h^{max} = 250\ GeV$

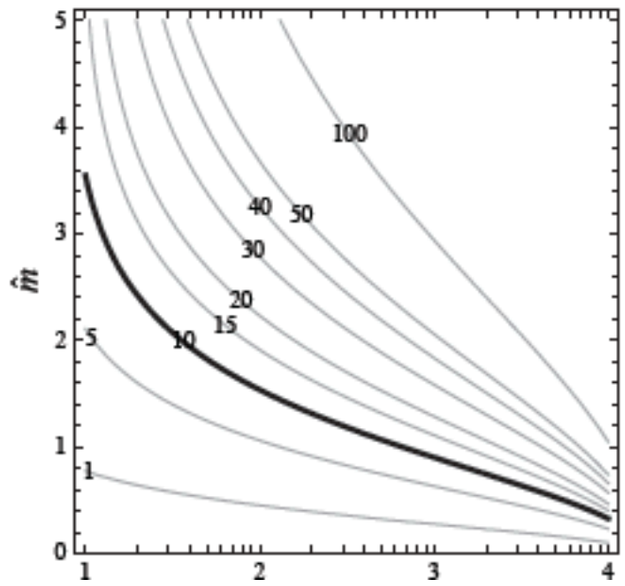


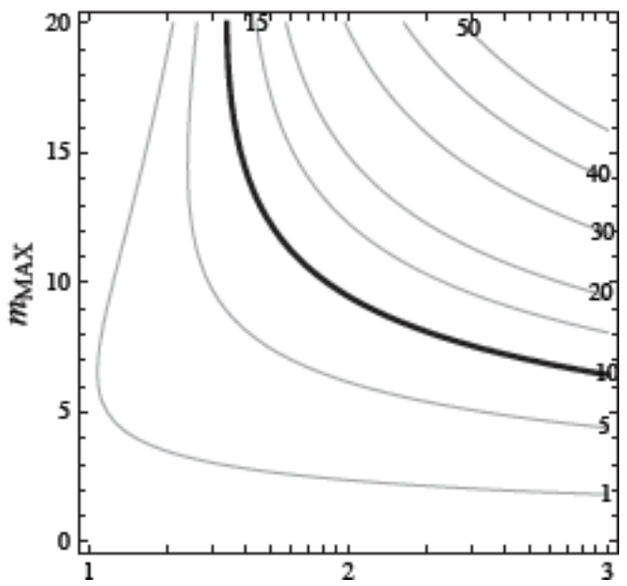




$\leftarrow \log_{10} \dfrac{M_{susy}}{TeV}$







$\hat{m}$ is $m_{\tilde{q}_{1,2}}$ with degenerate condition among $\tilde{f}$'s at M_{susy}
m_{MAX} is $m_{\tilde{q}_{1,2}}$ without any condition at M_{susy}

$\Rightarrow \quad m_{\tilde{q}_{1,2}} \gtrsim 10\ TeV$ OK in λSusy

4. Phenomenological consequences

✶ gluino pair production and decays

a preliminary study in B, Pappadopulo

✶ a largely unconventional Higgs sector

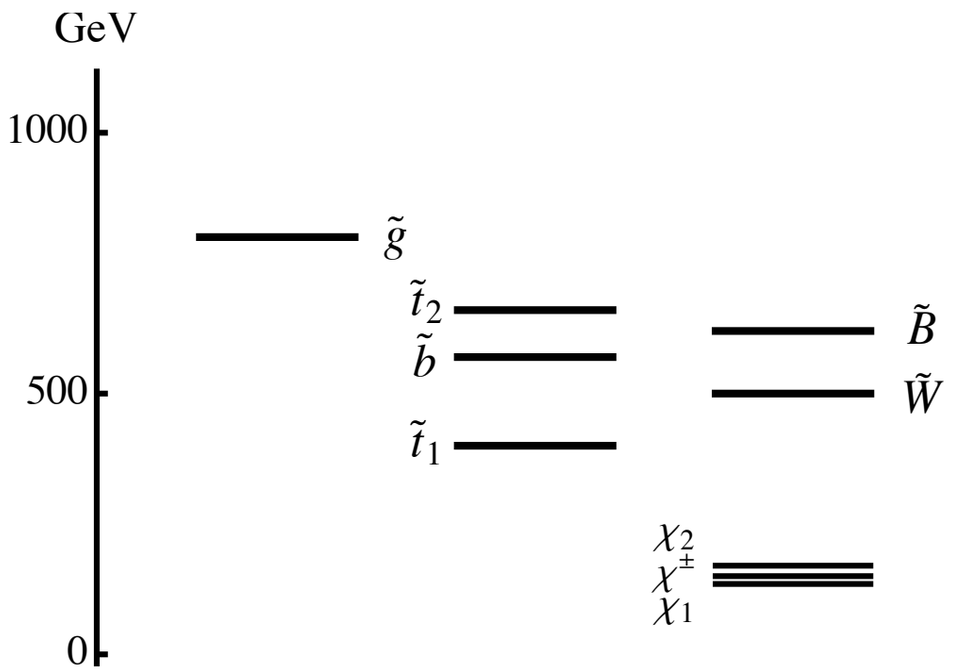
Cavicchia, Franceschini, Rychkov

✶ Dark Matter: relic abundance and detection affected

for the relic abundance in the MSSM, see
Arkani-Hamed, Delgado, Giudice

4.1 Gluino pair production and decays

A typical configuration



More in general

$$m_{\tilde{g}} = 400 \div 1800\ GeV$$
$$m_{\tilde{t}_1} < m_{\tilde{t}_2} < 800\ GeV \quad \theta_t = 0 \div \pi/2$$
$$\mu = 100 \div 400\ GeV$$
$$M_1,\ M_2 = 100 \div 500\ GeV$$
$$m_{\tilde{b}_R} \lesssim 600\ GeV$$

(s-lepton masses almost always unimportant)

3 relevant semi-inclusive BR's

$$\tilde{g} \to t\bar{t}\chi$$
$$\tilde{g} \to t\bar{b}\chi\ (\bar{t}b\chi)$$
$$\tilde{g} \to b\bar{b}\chi$$

with $B_{tt} + 2B_{tb} + B_{bb} \approx 1$

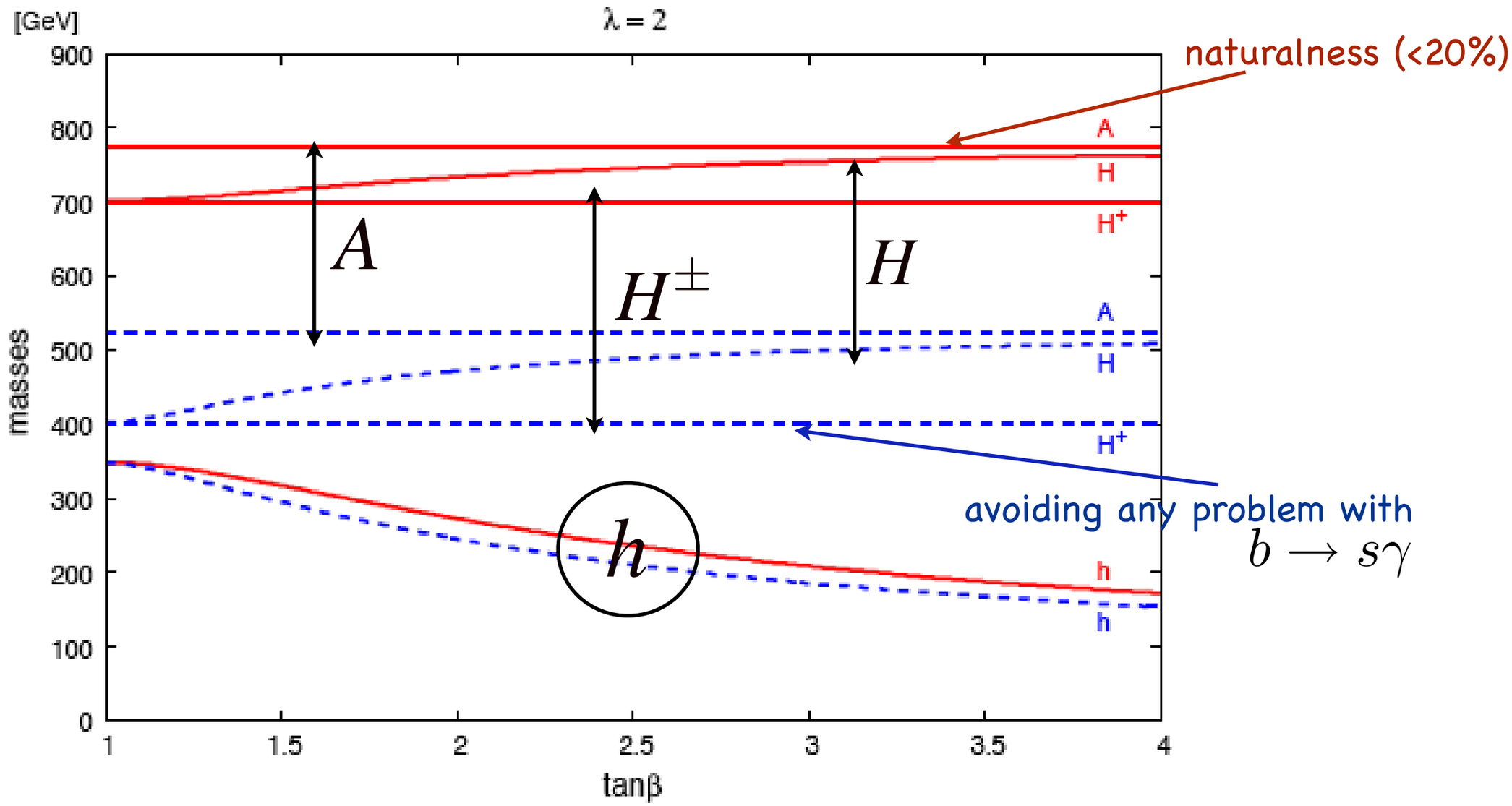
and $\chi = \chi_{LSP} + W, Z's$

⇒ "equal-sign" top's

⇒ spherical events

⇒ 4 b's always, sometime only

4.2 A largely unconventional Higgs sector



$h \to ZZ \to l^+l^- \; l^+l^-$ Easy and very much non-susy like

$H \to hh \to 4V \to l^+l^- \; 6j$ $BR \propto \lambda^2$ much larger than normal

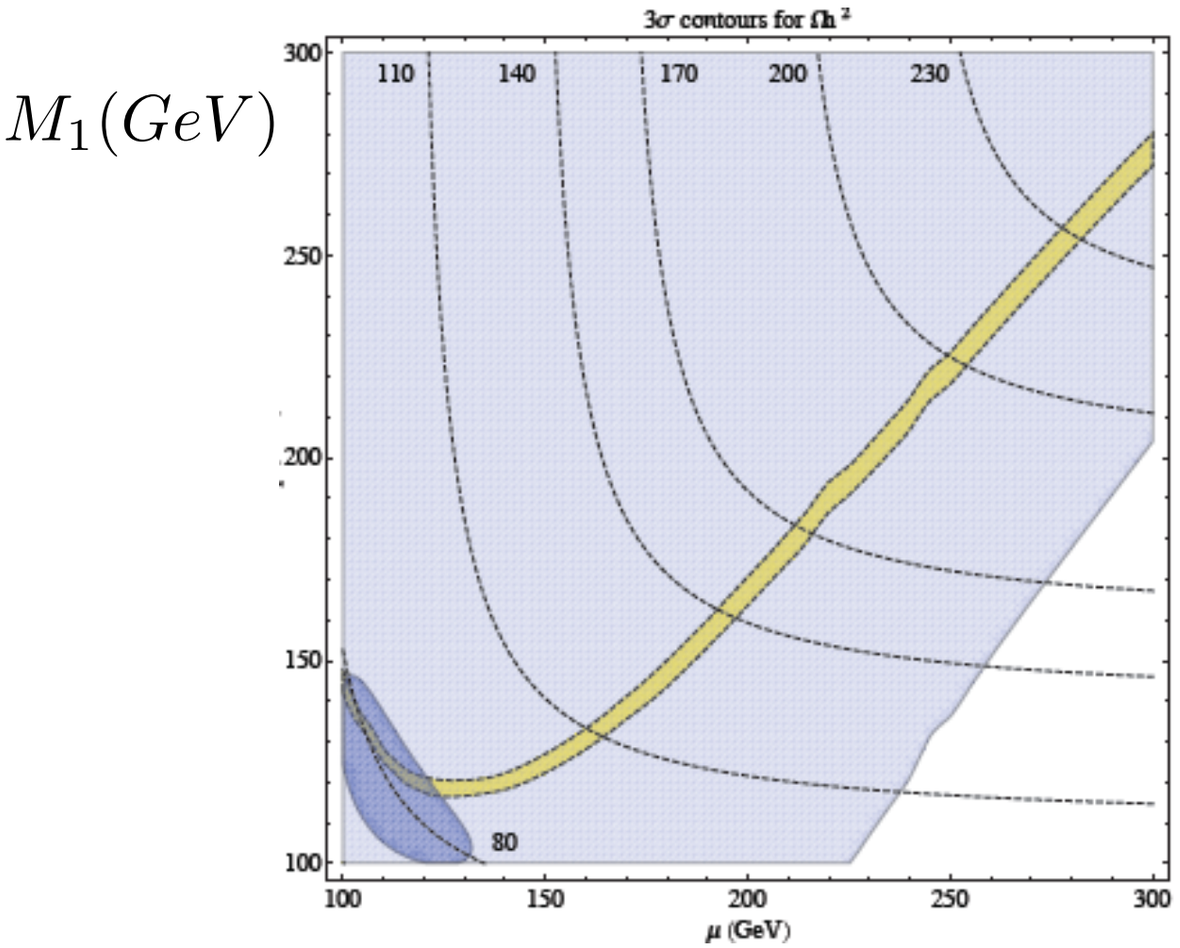
$A \to hZ \to VV \; Z \to l^+l^- \; 4j$

4.3 Dark Matter: relic abundance and detection

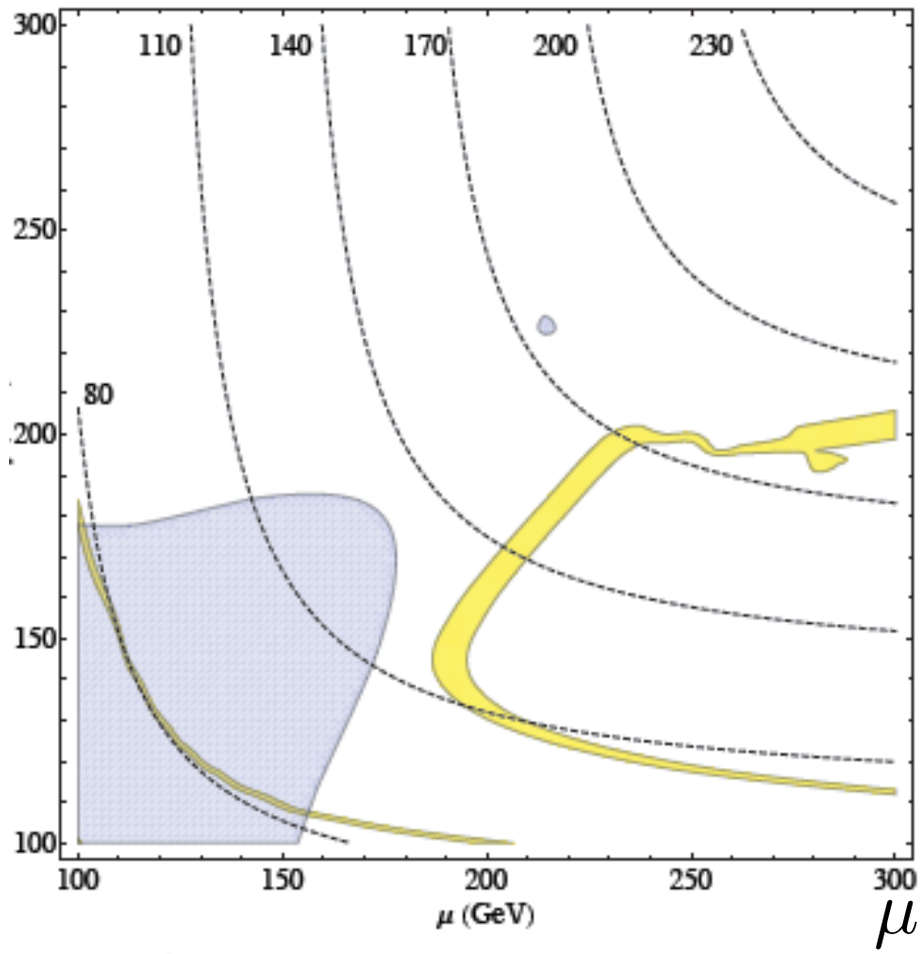
Relic abundance:

A strong effect of the s-channel heavier Higgs exchange
No need of "well-temperament"

M_2 large



MSSM $m_h = 120\ GeV$



λSusy: $m_h = 200\ GeV$

dark blu: CDMS now
light blu: XENON100

Direct detection affected by $\sigma \propto \frac{1}{m_h^4}$ and different mixing

Conclusions

✶ The Higgs boson and the flavour problems may be related and suggest considering a Non Standard Supersymmetric Spectrum where:

$$m_h = 200 \div 250\ GeV$$
$$m_{\tilde{f}_{1,2}} \gtrsim 10 \div 15\ TeV >> m_{\tilde{f}_3}$$

✶ Naturally possible at least in λSusy

✶ Phenomenology (peculiar):

$$\Rightarrow \quad \tilde{g} \to t\bar{t}\chi,\ t\bar{b}\chi\ (\bar{t}b\chi),\ b\bar{b}\chi$$
$$\Rightarrow \quad h \to ZZ,\ H \to hh,\ hhh$$
$$\Rightarrow$$ DM: no "well-temperation" needed
Direct Detection affected

✶ Flavour signals from the 1-2/3 effect (and low $\tan\beta$)

ElectroWeak Precision Tests in λSUSY

$$\lambda(G_F^{-1/2}) \approx 2$$

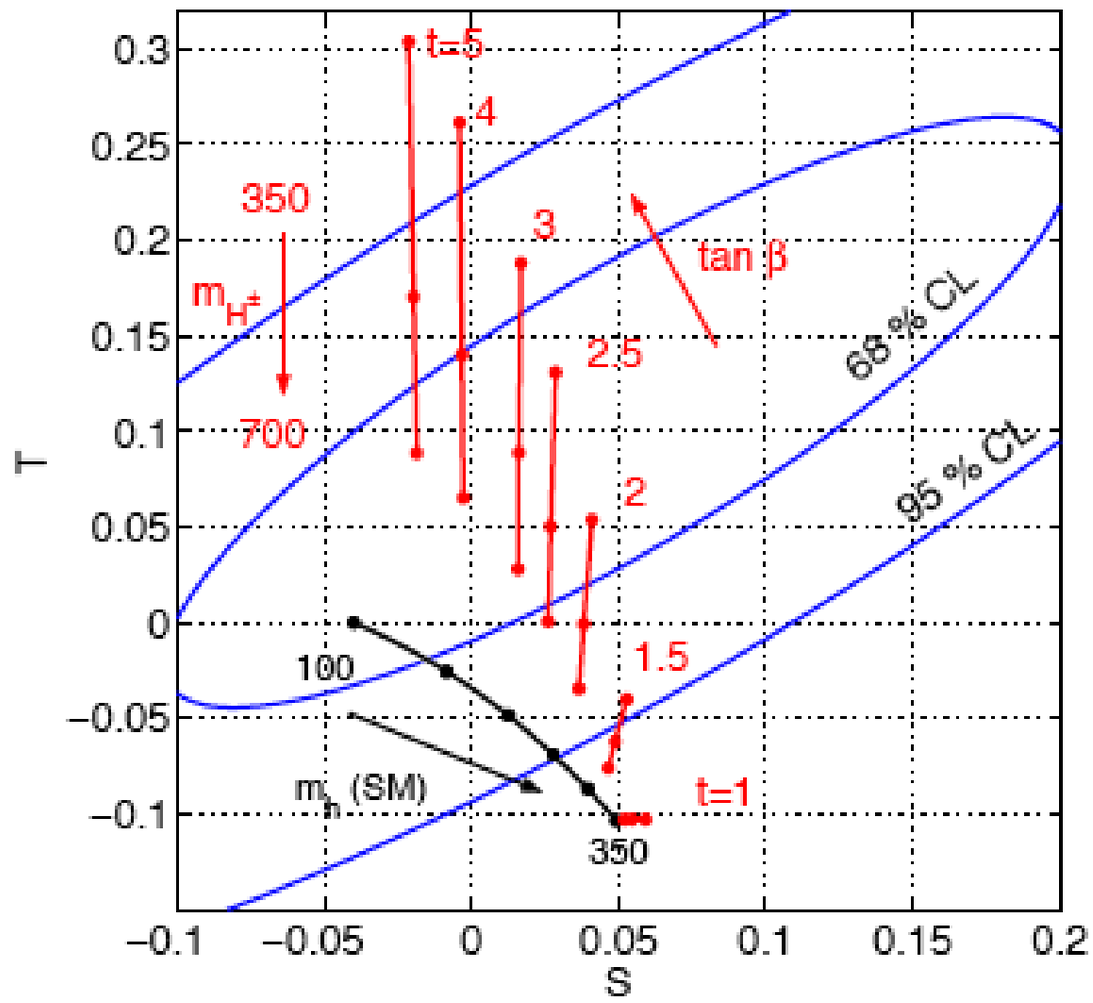
one loop effects but

$$\Delta T \propto \lambda^4$$

$$\lambda \uparrow \Rightarrow m_h \uparrow$$

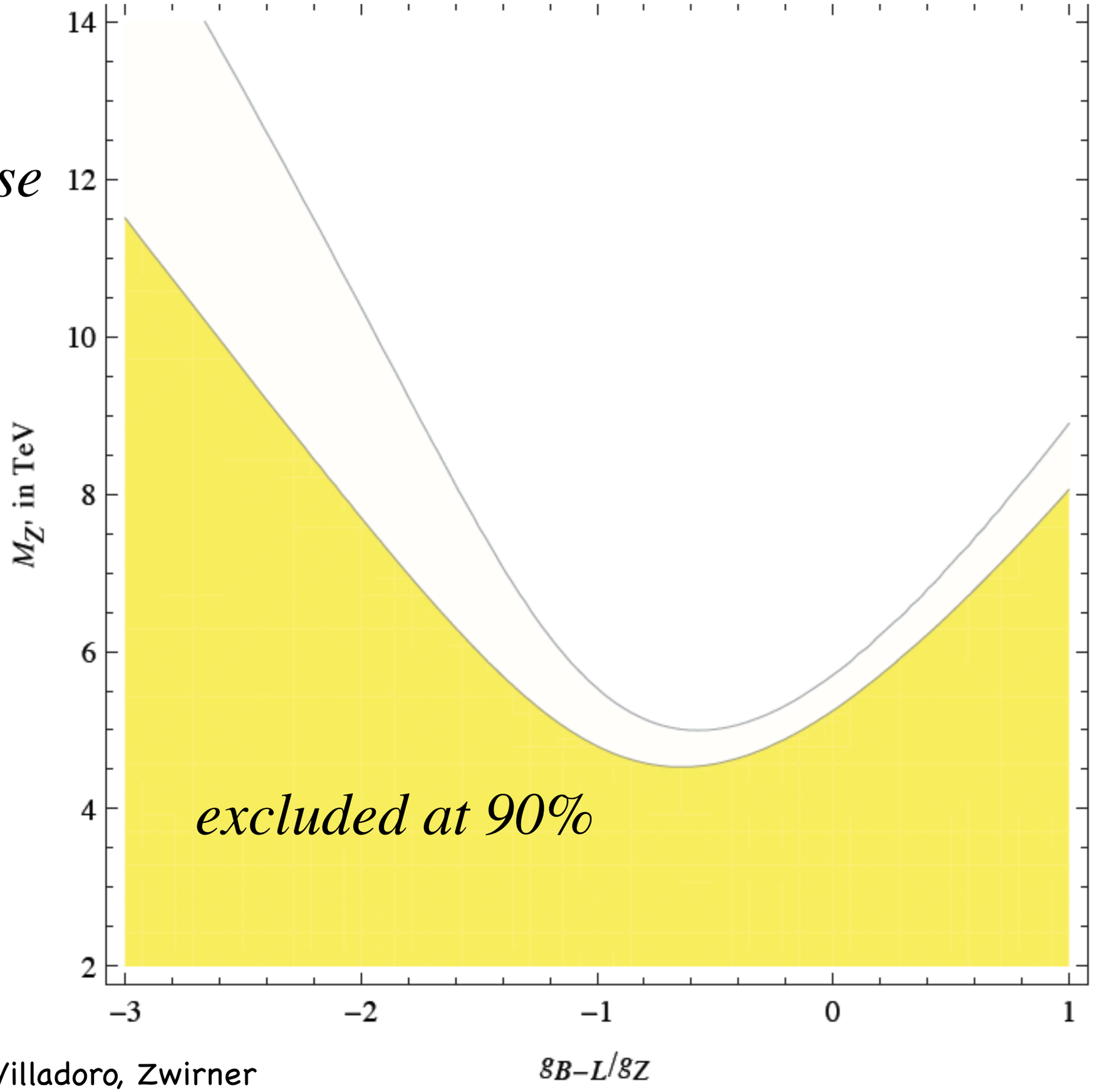
compensated by ΔT ↑

S and T from Higgs's



(an example of how we could be fouled by the EWPT)

extra U(1) case



Salvioni, Strumia, Villadoro, Zwirner

4.3 Dark Matter: relic abundance and detection

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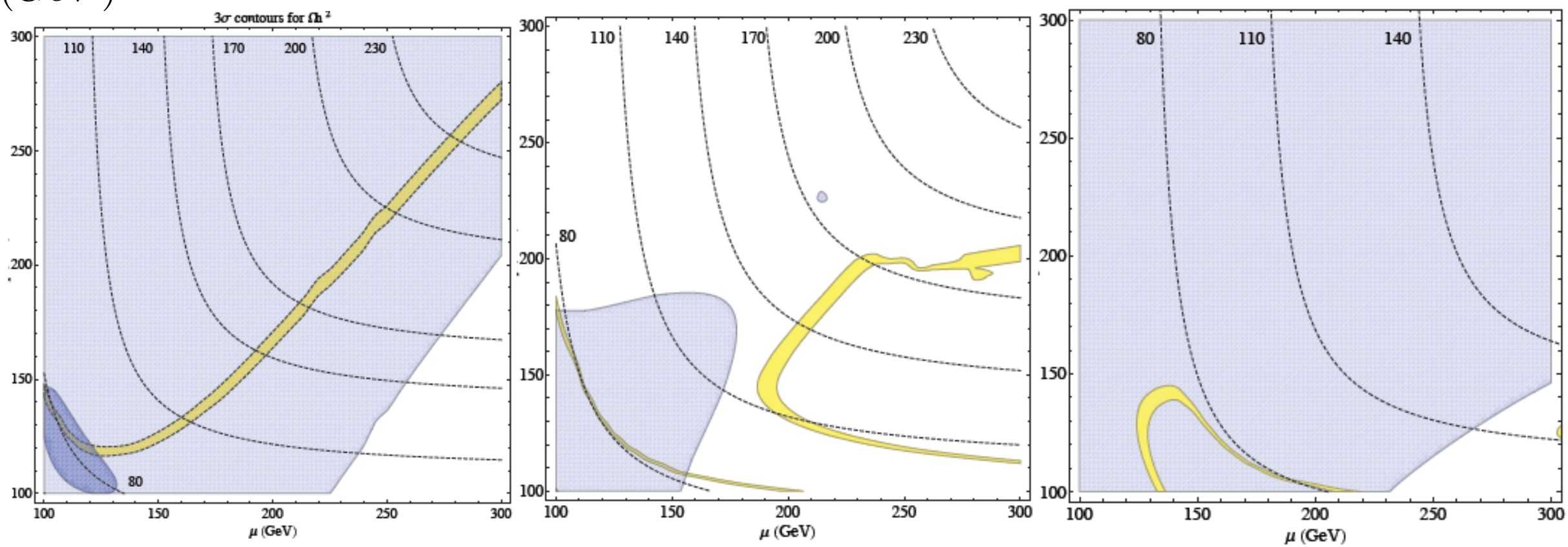
No need of "well-temperament"

$M_1(GeV)$ M_2 large M_2 large $M_2 = 200\ GeV$



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