A Non Standard Supersymmetric Spectrum

A bottom-up viewpoint

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B, Bertuzzo, Farina, Lodone, Pappadopulo

2 methodological questions

1. Is it useful to start with a praise of the MSSM?

2. Is it useful to consider significant variations of the MSSM?

EWPT ⇑⇓

unification ⇓

no s-particle so far ⇑

no Higgs boson ⇑

no flavour signal ⇑

1. Motivations: a matter of naturalness, once again

(supersymmetry could be there and we might never know)

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

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

hence the Higgs mass problem

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

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

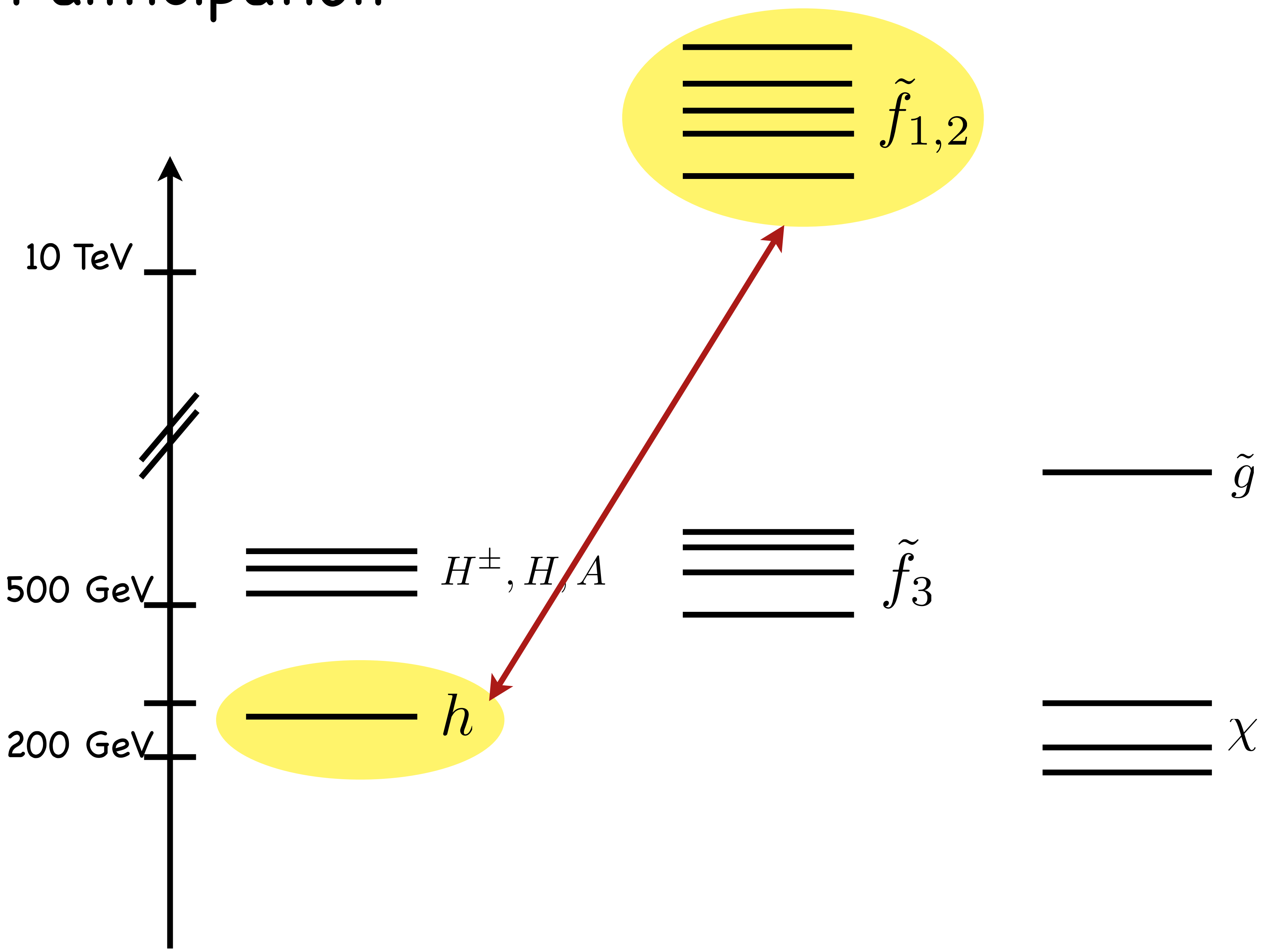
$\overset{?}{\Leftrightarrow}$ the flavour problem

Related problems?

Enough to try to go beyond the MSSM?

A Non Standard Supersymmetric Spectrum

An anticipation



Motivated? If yes, can it be naturally implemented?
Which consequences?

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

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

1. With no degeneracy, nor alignment

$m_{\tilde{f}_{1,2}}$ in the hundreds of TeV

Giudice, Nardecchia, Romanino

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 $\delta^{LL} \approx \delta^{RR} >> \delta^{LR}$

Real ΔS=2 $\quad m_{\tilde{q}_{1,2}} \gtrsim 18\ TeV$

Im ΔS=2, $\sin\phi_{CP} \approx 0.3$ $\quad m_{\tilde{q}_{1,2}} \gtrsim 120\ TeV$

3. As in 2, but with $\delta^{LL} >> \delta^{RR}, \delta^{LR}$ (or $\delta^{RR} >> \delta^{LL}, \delta^{LR}$)

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

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

(EDM's give somewhat weaker constraints)

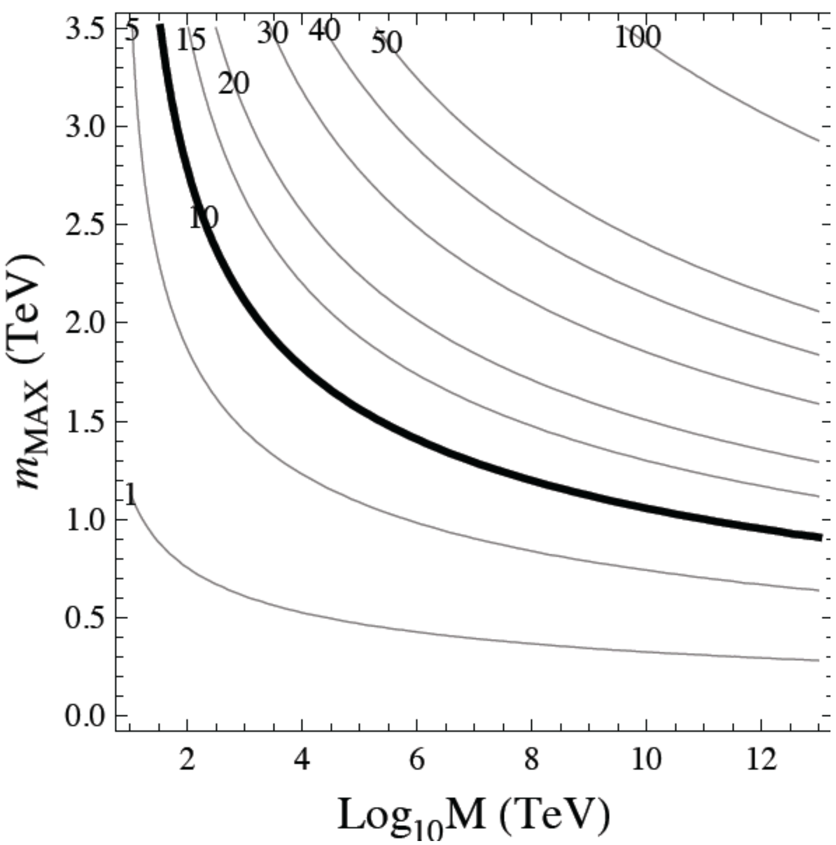
$\Rightarrow \quad m_{\tilde{f}_{1,2}} \gtrsim 20 \div 30\ TeV \quad m_{\tilde{f}_3} \approx 0.5 \div 1\ TeV$

may be a way to solve the flavour problem

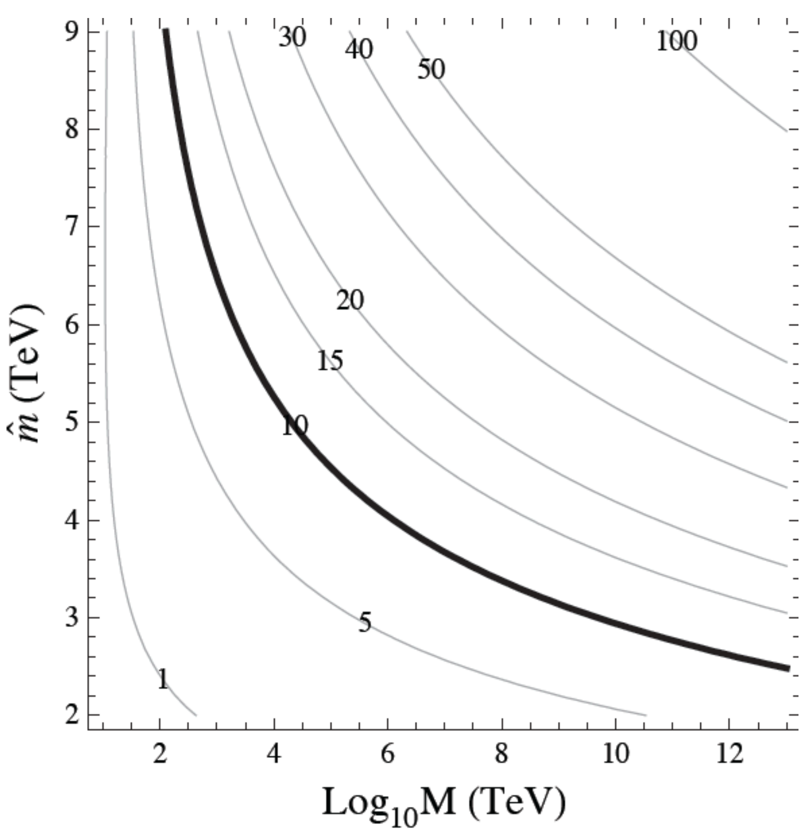
Bounds on $m_{\tilde{q}_{1,2}}$ from $\frac{m^2_{\tilde{q}_{1,2}}}{m_h^2}\frac{\delta m_h^2}{\delta m^2_{\tilde{q}_{1,2}}} < \Delta$

$$\frac{\partial m_h^2}{\partial t} \approx \frac{\alpha'}{4\pi} Tr(Y\tilde{m}^2_{1,2}) + \frac{\alpha^2}{16\pi^2}\tilde{m}^2_{1,2}$$

Dimopoulos, Giudice



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



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

x≈ $\frac{m_h}{m_Z}$

⇒ For $m_{\tilde{f}_{1,2}} \gtrsim 20 \div 30\ TeV$ best to have $\frac{m_h}{m_Z} \gtrsim 2 \div 3$ thus addressing the Higgs mass problem as well

3. Supersymmetry without a light Higgs boson

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

★ Extra U(1)

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

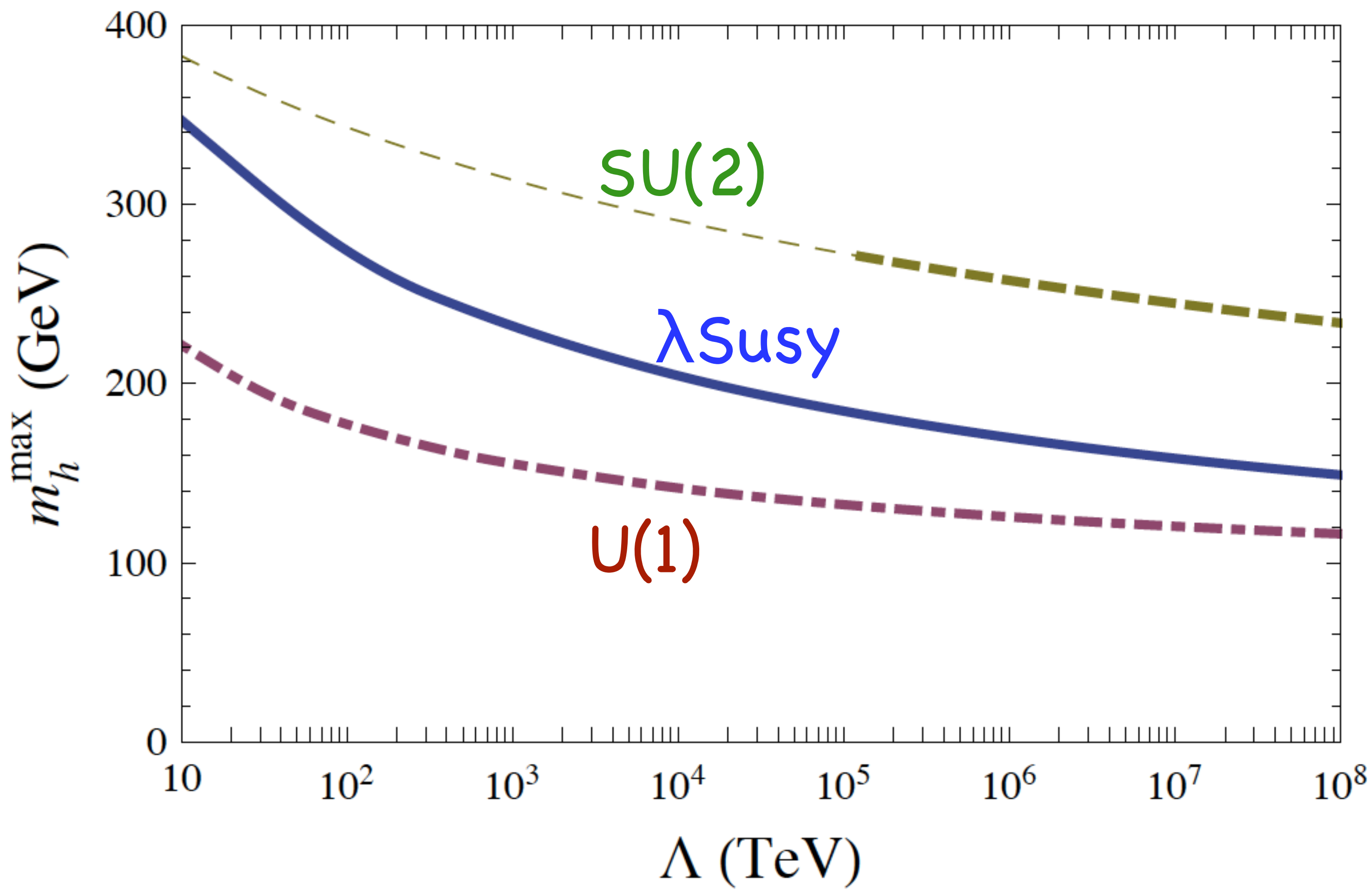
★ Extra SU(2)

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

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

★ $\Delta f = \lambda S H_1 H_2$

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



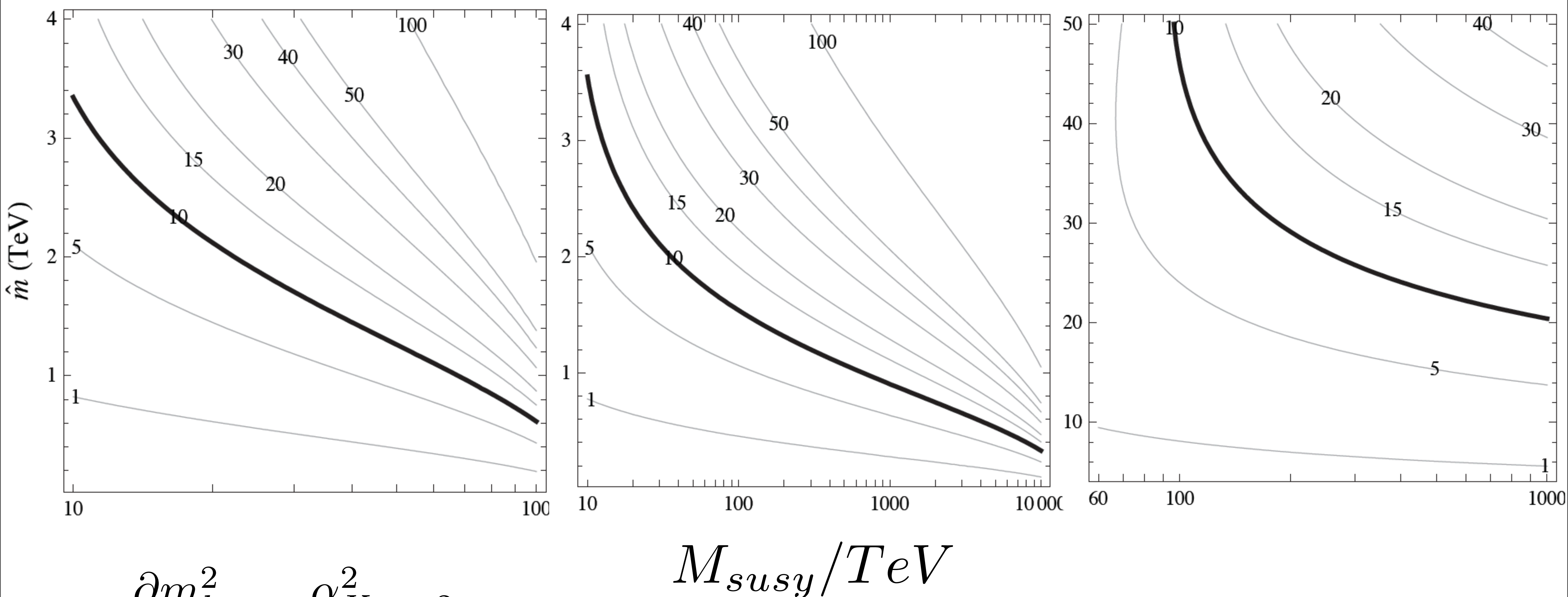
Λ is the scale at which some coupling gets semi-perturbative
(what happens above Λ not our concern, more later)

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

Batra, Delgado, Kaplan, Tait
Harnik, Kribs, Larson, Murayama
B, Hall, Nomura, Rychkov

Naturalness bounds

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



$$\frac{\partial m_h^2}{\partial t} \approx \frac{\alpha_X^2}{16\pi^2}\tilde{m}_{1,2}^2$$

$\hat{m}$ is $m_{\tilde{f}_{1,2}}$ with vertical degeneracy among $\tilde{f}$'s at M_{susy}

$\Rightarrow$ $m_{\tilde{f}_{1,2}} \gtrsim 20\ TeV$ OK in λSusy at M = 100÷1000 TeV

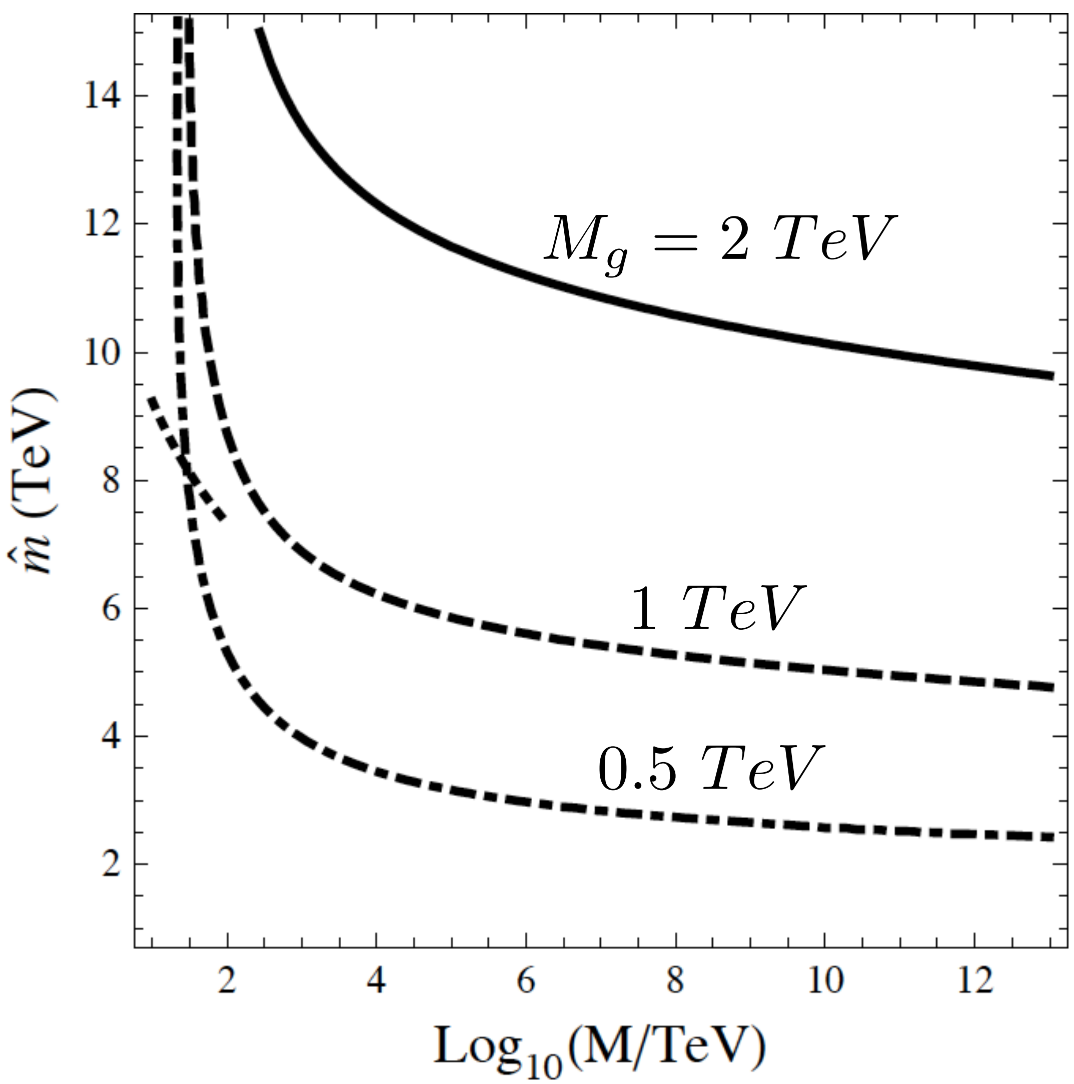
Colour/em conservation

Arkani-Hamed, Murayama

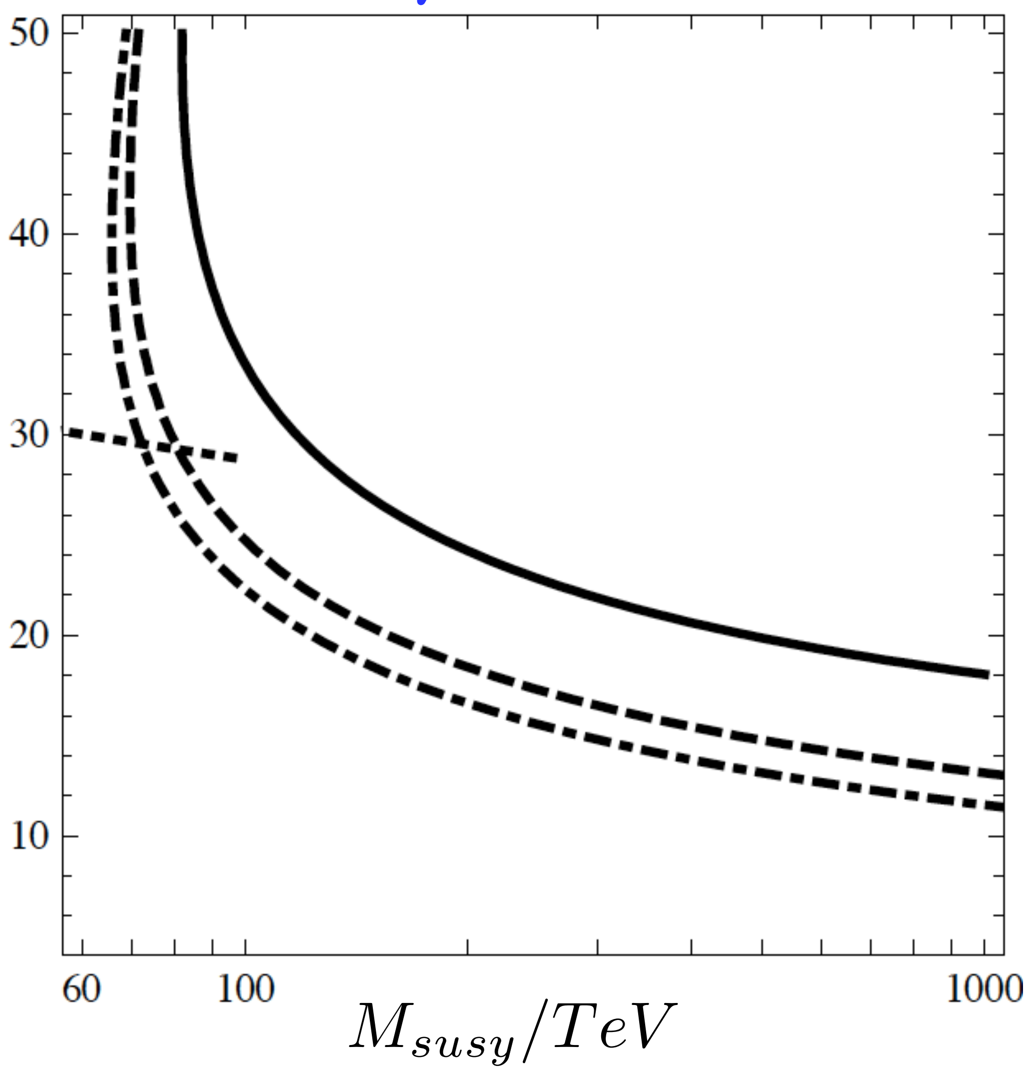
$$\frac{dm^2_{\tilde{Q}_3}}{d\log\mu} \approx -\frac{\alpha_S}{4\pi}M_g^2 + \frac{\alpha_S^2}{16\pi^2}\hat{m}^2_{1,2}$$

Require $m^2_{\tilde{Q}_3} > 0$ for natural $m^2_{\tilde{Q}_3}(M)$

MSSM $m_h^{max} = 90\ GeV$



λSusy $m_h^{max} = 250\ GeV$



ElectroWeak Precision Tests in λSUSY

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

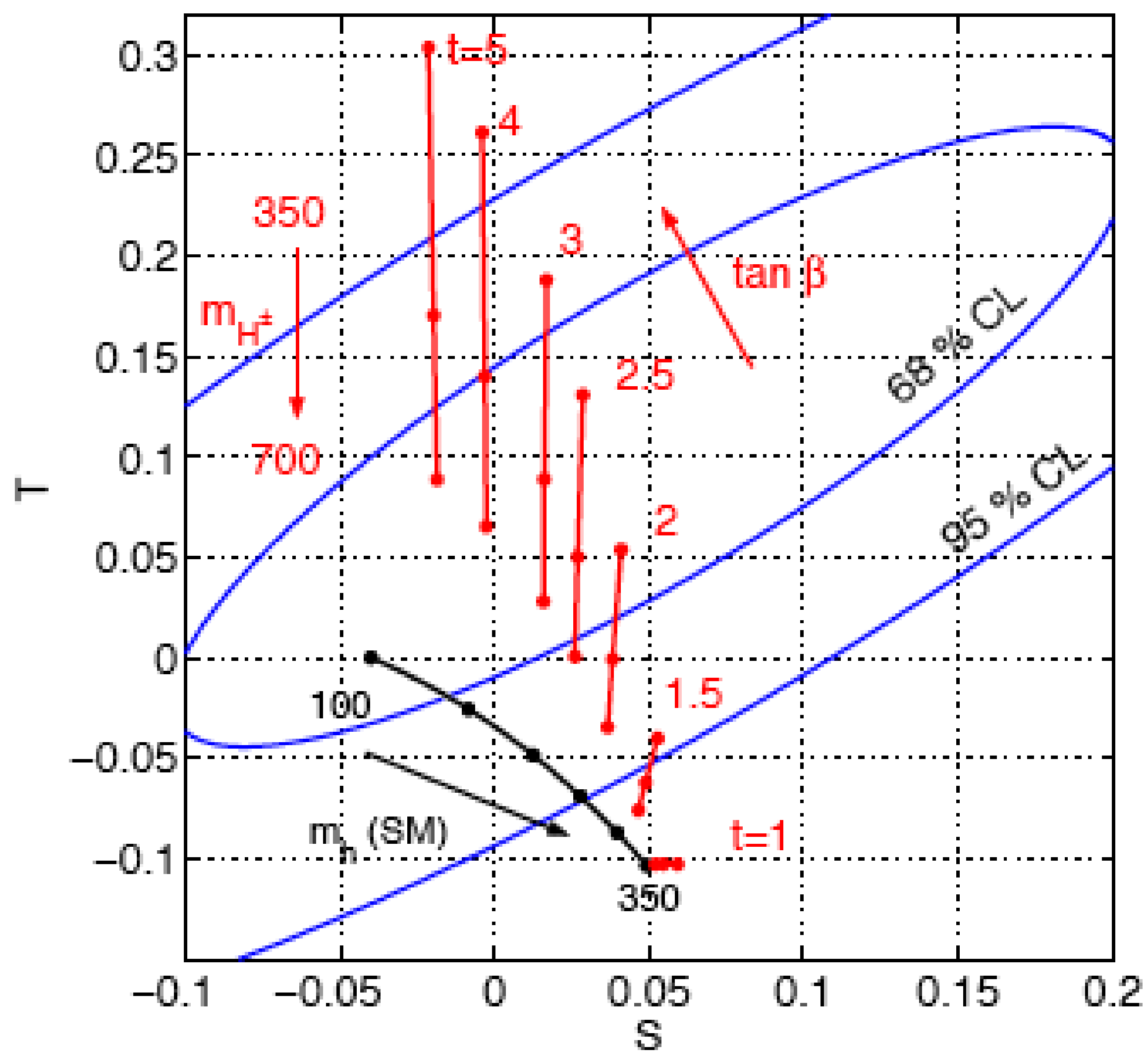
S and T from Higgs's

one loop effects but

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

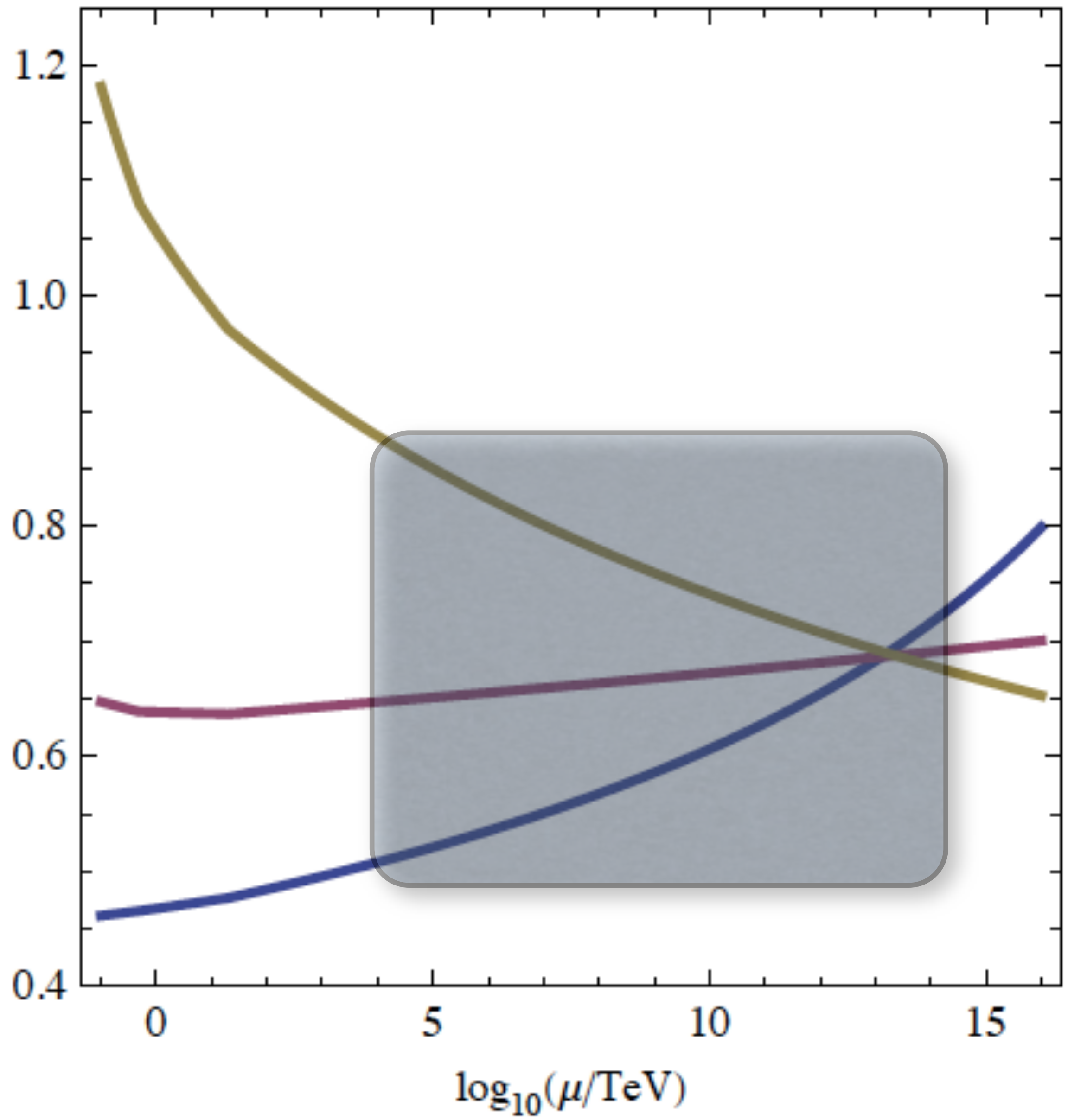
$$\lambda \uparrow \Rightarrow m_h \uparrow$$

compensated by $\Delta T \uparrow$



B, Hall, Nomura, Rychkov

What about unification?



It depends on what happens at $M \gtrsim 10^4 TeV$

At $M \approx 10^4\ TeV$:

$g_1 \approx 0.5,\ g_2 \approx 0.7,\ g_3 \approx 0.85$

4. Phenomenological consequences

- ✶ gluino pair production and decays

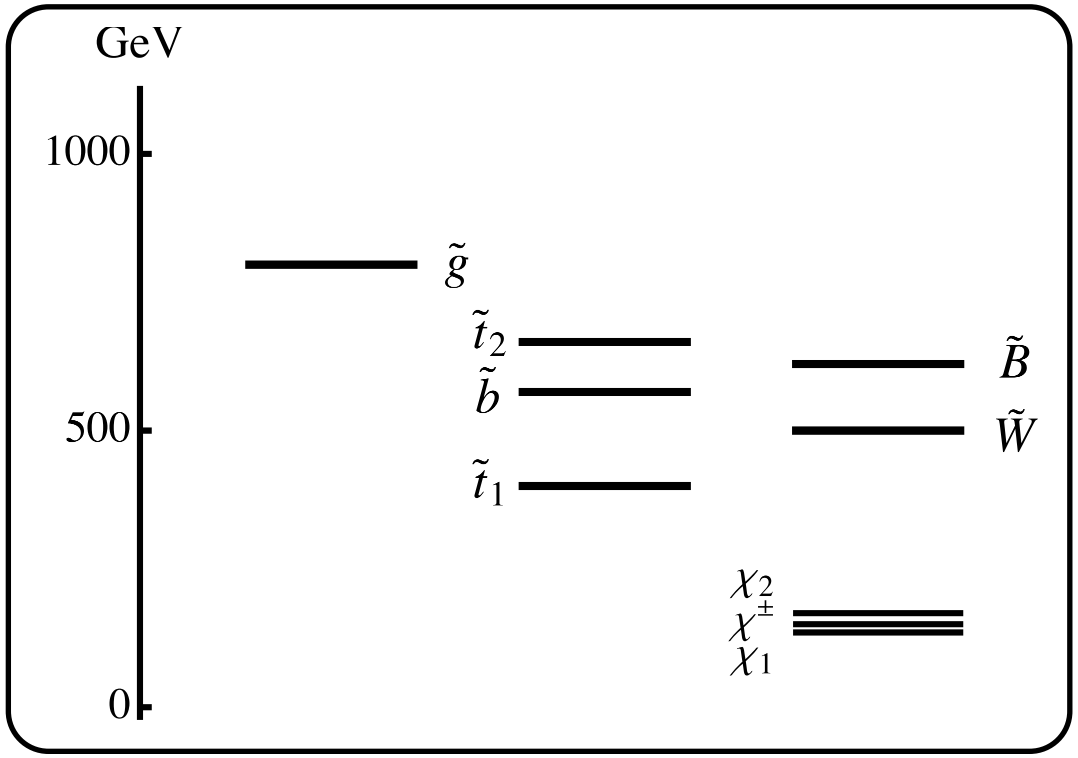
- ✶ a largely unconventional Higgs sector

Cavicchia, Franceschini, Rychkov

- ✶ Dark Matter: relic abundance and detection affected

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

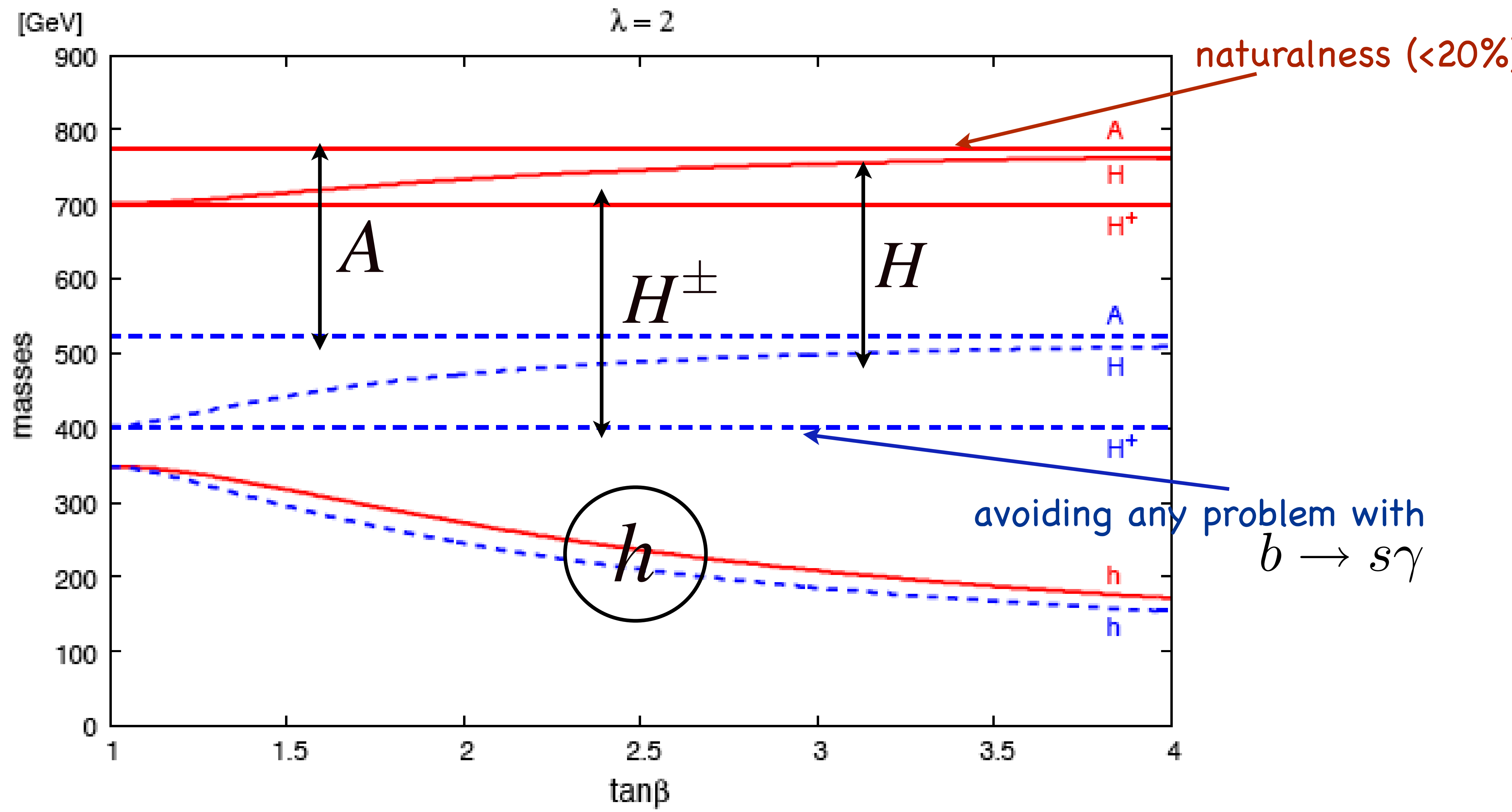
and $\quad \chi = \chi_{LSP} + W, Z's$

⇒ multi top events

⇒ 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

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

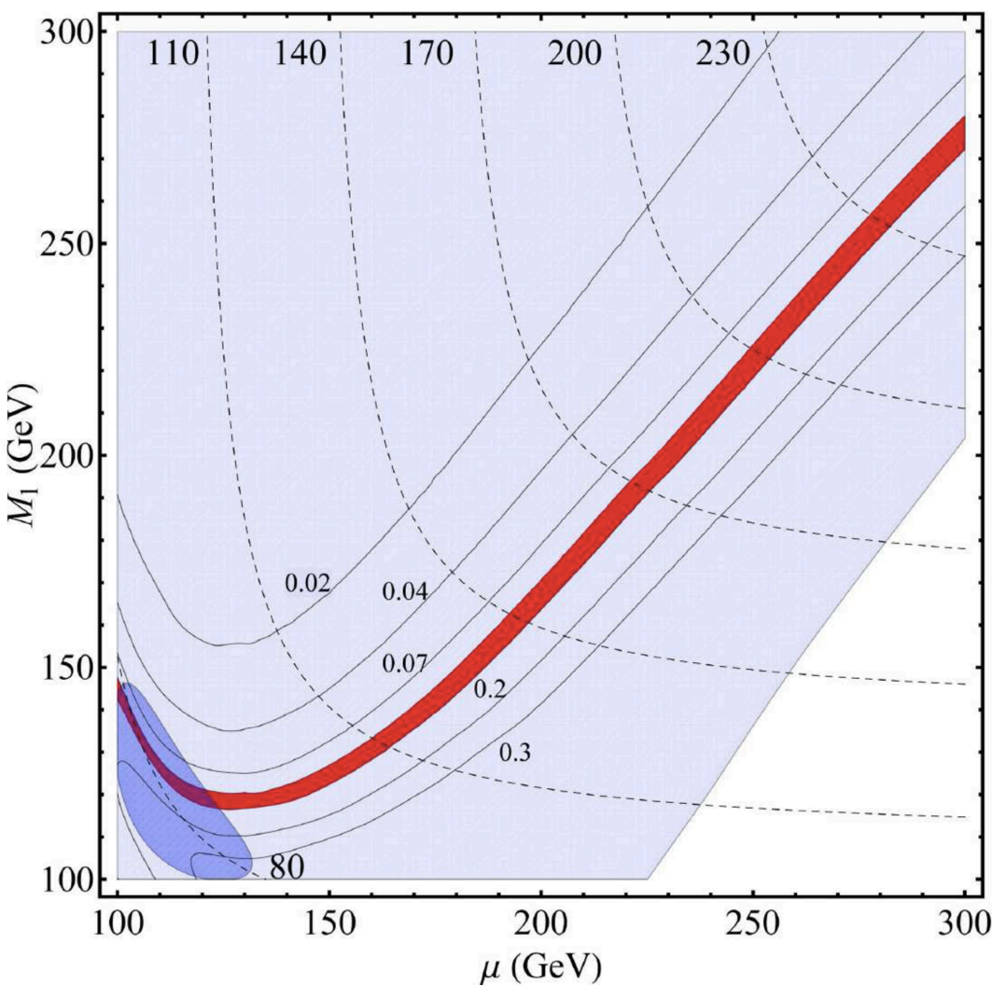
4.3 Dark Matter: relic abundance and detection

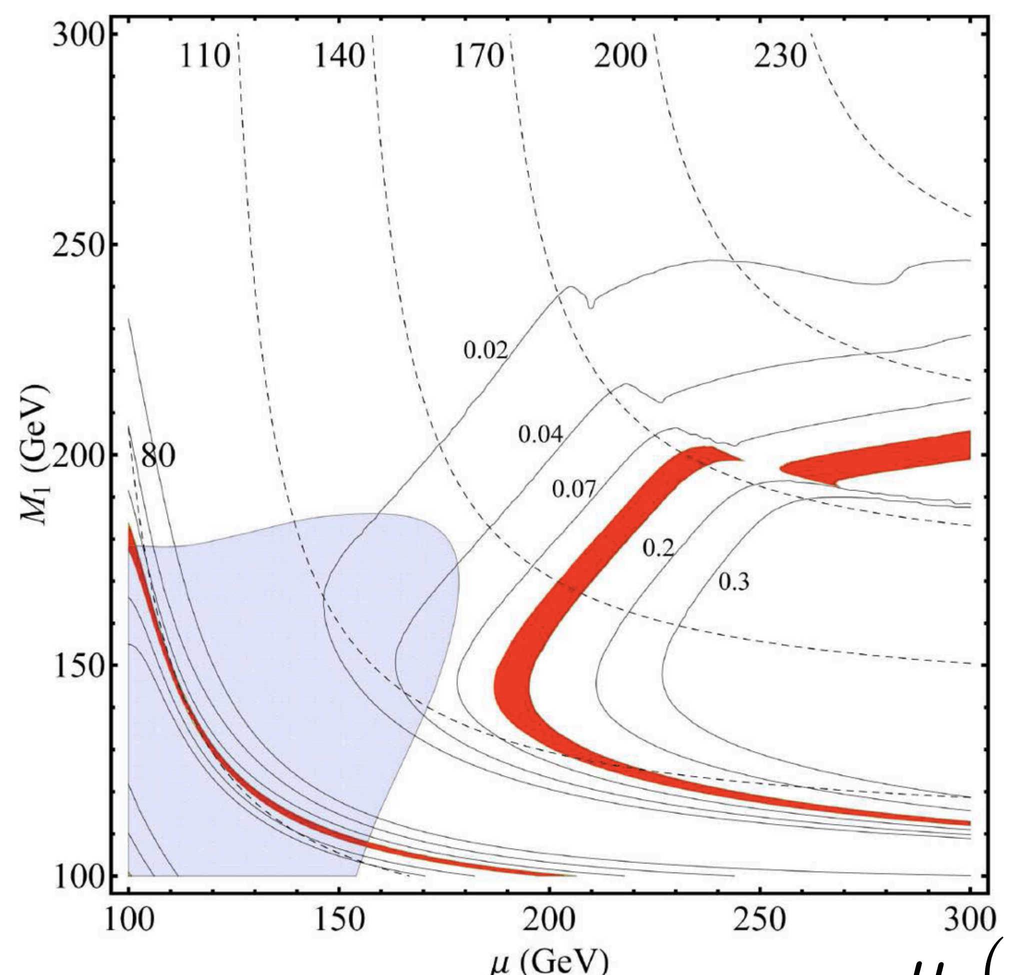
Relic abundance:

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

M_2 large

$M_1 (GeV)$





$\mu \ (GeV)$

MSSM $m_h = 120\ GeV$

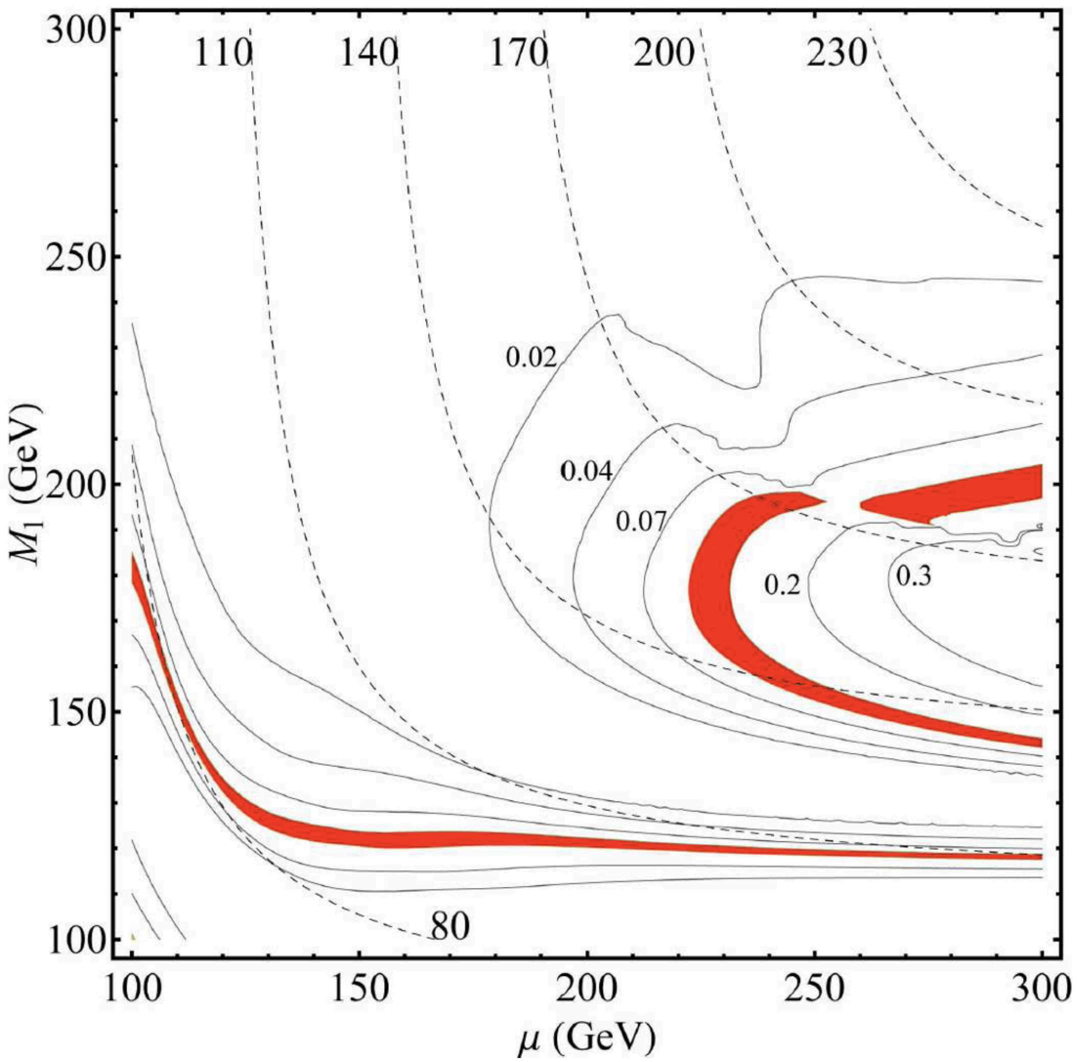
λSusy: $m_h = 200\ GeV$

dark blu: CDMS now
light blu: "XENON100"

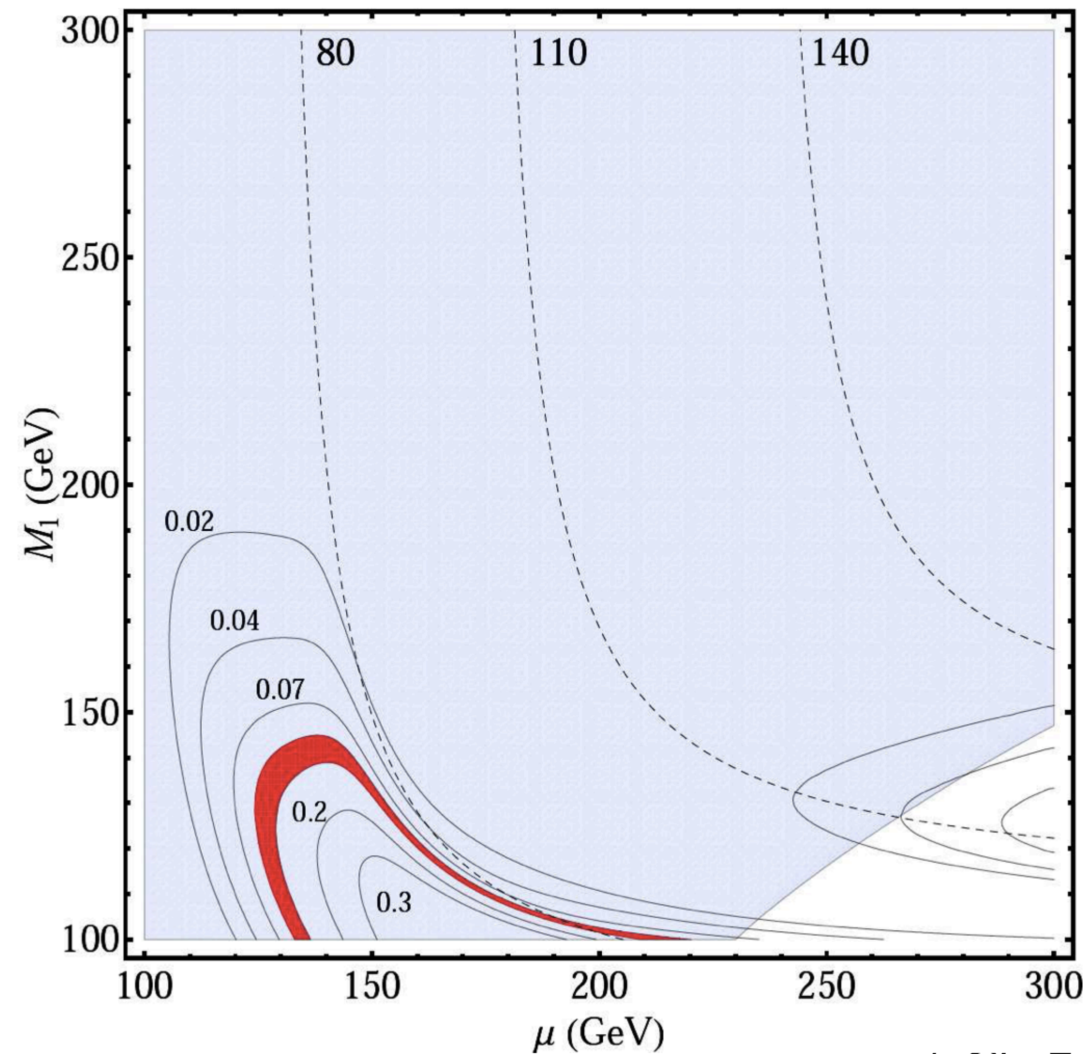
Direct detection affected by $\sigma \propto \frac{1}{m_h^4}$ and different mixing

4.3 Dark Matter: relic abundance and detection

$M_1 (GeV)$ M_2 large



$M_2 = 200\ GeV$



$\mu\ (GeV)$

λSusy: $m_h = 250\ GeV$

dark blu: CDMS now
light blu: "XENON100"

Conclusions

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

$$m_h = 200 \div 250\ GeV$$

$$m_{\tilde{f}_{1,2}} \gtrsim 20 \div 30\ TeV >> m_{\tilde{f}_3}$$

✶ Naturally possible at least in λSusy

✶ Phenomenology (peculiar):

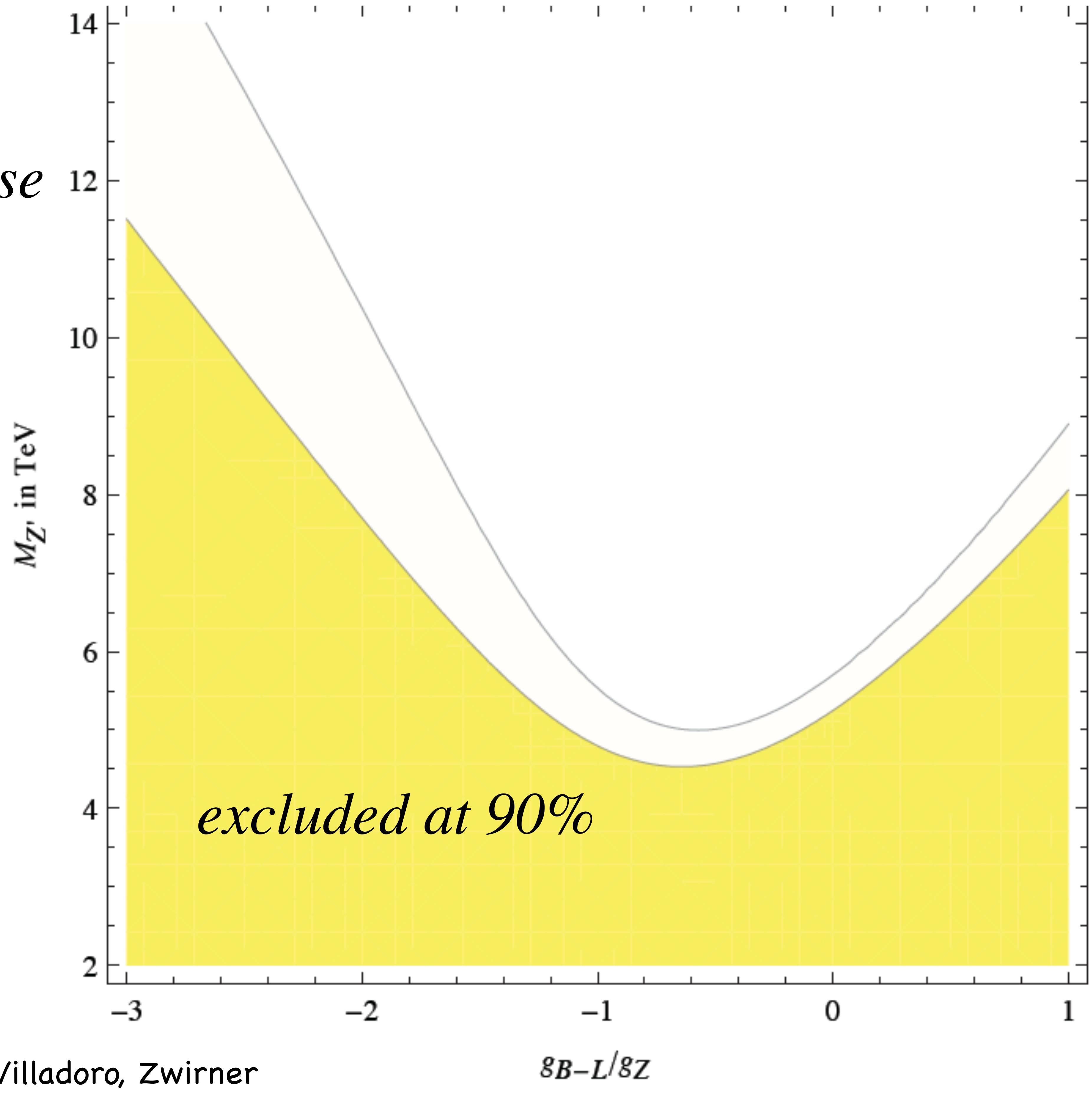
$\Rightarrow \quad \tilde{g} \to t\bar{t}\chi,\ t\bar{b}\chi\ (\bar{t}b\chi),\ b\bar{b}\chi$

$\Rightarrow \quad h \to ZZ,\ H \to hh,\ hhh$

$\Rightarrow$ DM: no "well-temperation"
Direct Detection affected

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

extra U(1) case



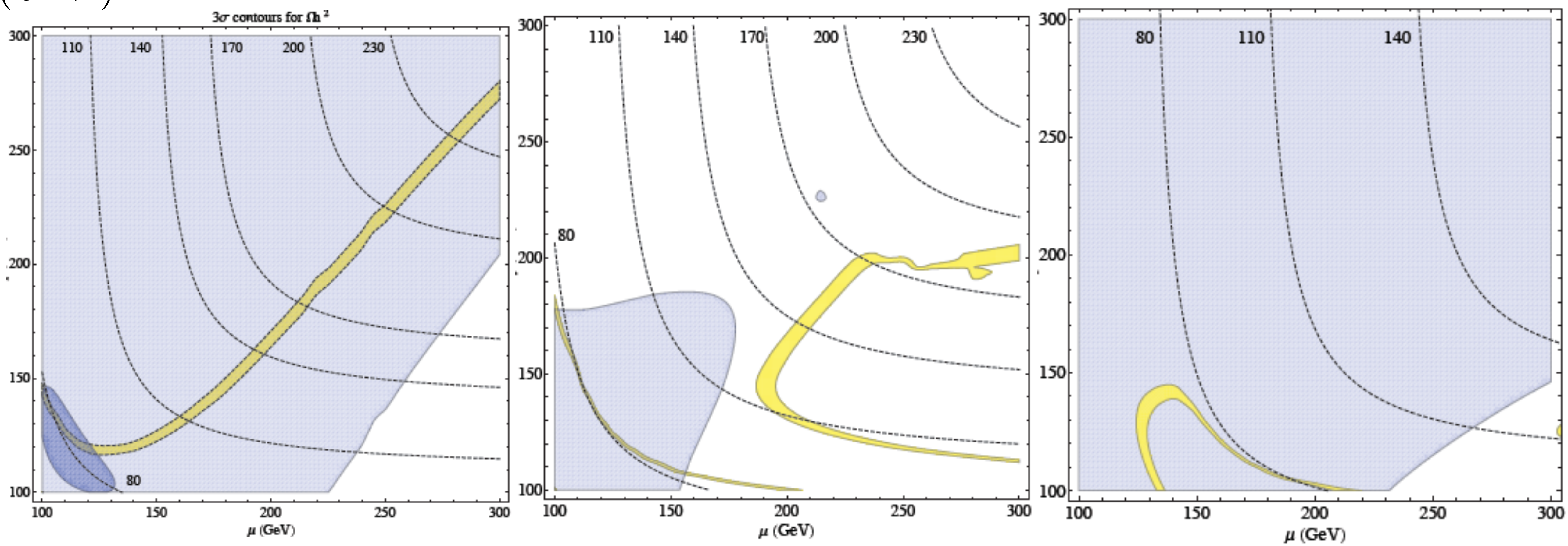
Salvioni, Strumia, Villadoro, Zwirner

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"

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



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