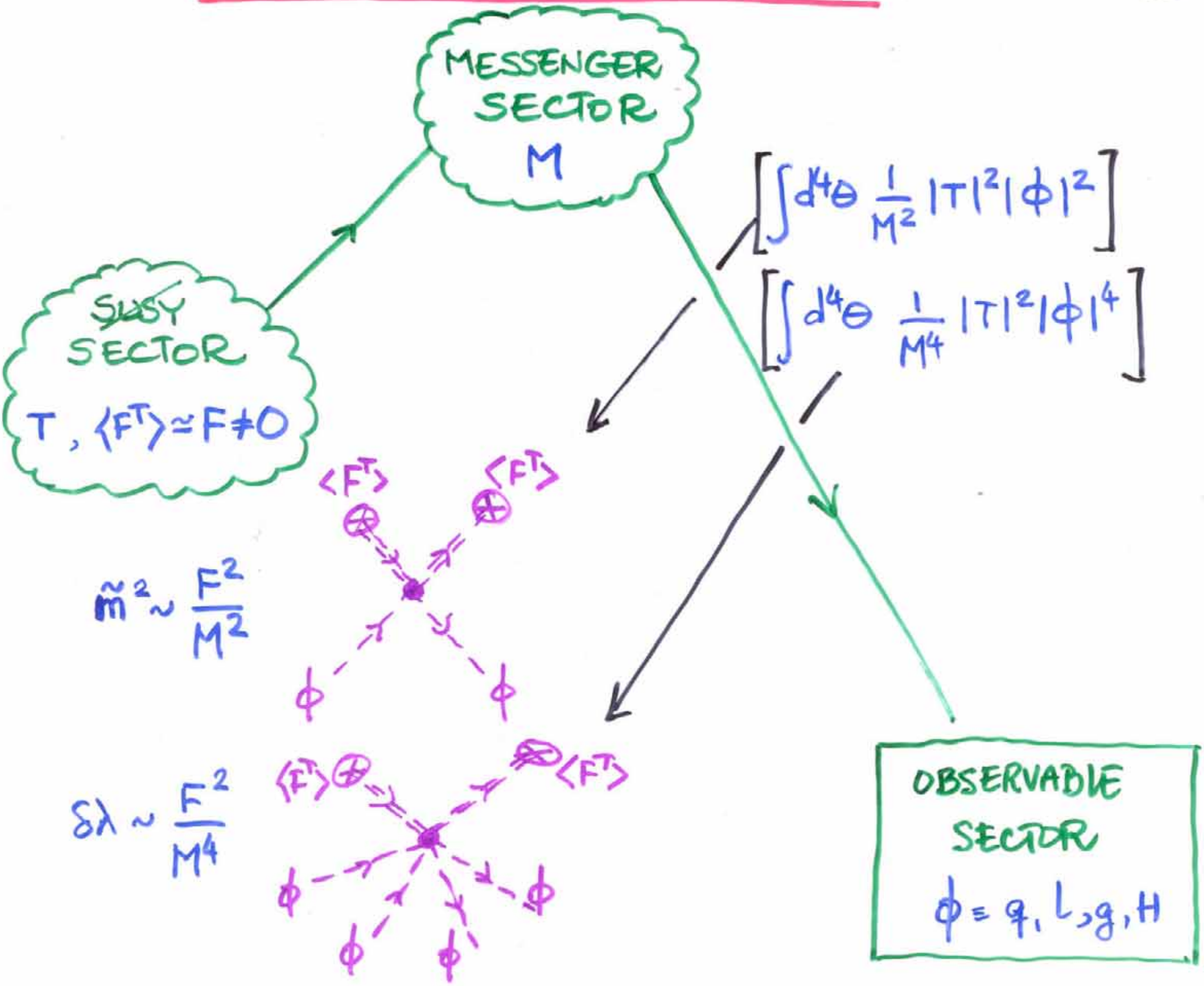
CONCLUSIONS

LOW $\sqrt{F}$ SUSY BREAKING IS A QUITE INTERESTING POSSIBILITY!

- ⇨ UNCONVENTIONAL HIGGS SECTOR (AND OTHERS)
- ⇨ NEW OPTIONS FOR ELECTROWEAK SYMMETRY BREAKING
- ⇨ DRAMATIC REDUCTION OF FINE-TUNING IS POSSIBLE

SUSY BREAKING



WHAT IS THE SCALE OF ~~SUSY~~ ?

$\tilde{m} \sim \frac{F}{M} \lesssim O(\text{TeV})$ leaves $\sqrt{F}$ free

1) Very high scale ~~SUSY~~ (Gravity mediation)

$M \sim 10^{18}\,\text{GeV} \gg \sqrt{F} \sim 10^{11}\,\text{GeV} \gg \tilde{m} \lesssim \text{TeV}$

$\delta\lambda \sim \frac{F^2}{M^4} \sim 10^{-30}$ Negligible

2) Low scale ~~SUSY~~

$M \sim \text{TeV} \gtrsim \sqrt{F} \sim \text{TeV}$ $\Rightarrow$ Sizable $\delta\lambda \sim \frac{F^2}{M^4}$

Pobusky, Su

EW BREAKING REVISITED

Effective theory approach to describe SUSY

Brignole, Feruglio, Zwirner

$\mathcal{L}_{eff}$ → Non-renormalizable interactions $T \leftrightarrow \phi$

HIGGS POTENTIAL :

$$V = m_1^2 |H_1|^2 + m_2^2 |H_2|^2 + (m_3^2 H_1 \cdot H_2 + h.c.)$$
$$+ \frac{1}{2}\lambda_1 |H_1|^4 + \frac{1}{2}\lambda_2 |H_2|^4 + \lambda_3 |H_1|^2 |H_2|^2 + \lambda_4 |H_1 \cdot H_2|^2$$
$$+ \left[\frac{1}{2}\lambda_5 (H_1 \cdot H_2)^2 + \lambda_6 |H_1|^2 H_1 \cdot H_2 + \lambda_7 |H_2|^2 H_1 \cdot H_2 + h.c.\right]$$

⇨ TWO-HIGGS-DOUBLET MODEL with

$$m_i^2 \sim \mathcal{O}(F^2/M^2) \sim \mu^2$$

$$\lambda_i \sim \underbrace{\mathcal{O}(g^2)}_{\text{SUSY part like MSSM}} + \mathcal{O}(F^2/M^4)$$

⇨ MANY UNCONVENTIONAL POSSIBILITIES FOR EWSB

AND CHANGES W.R.T. MSSM

★ Tree-level EWSB is now possible

(radiative breaking not required)

★ Less constrained Higgs spectrum

→ MSSM mass rules for $h^0, H^0, A^0, H^\pm$ violated

→ All can be much heavier than Z^0

★ Extra (complex) d.o.f. in scalar sector

from singlet T

★ $\lambda_5, \lambda_6, \lambda_7 \neq 0$

New possible sources of $\not{CP}$

A CONCRETE MODEL

BCEN'03

$$W = \Lambda_S^2 T + \mu H_1 \cdot H_2 + \frac{l}{2M}(H_1 \cdot H_2)^2 \; ; \; \tilde{m} \equiv \frac{\sqrt{F_T}^2}{M} = \frac{\Lambda_S^2}{M}$$

$$K = |T|^2 + |H_i|^2 - \frac{\alpha_t}{4M^2}|T|^4 + \frac{\alpha_1}{M^2}|T|^2\left(|H_1|^2+|H_2|^2\right) + \frac{e_1}{2M^2}\left(|H_1|^4+|H_2|^4\right)$$

HIGGS POTENTIAL:

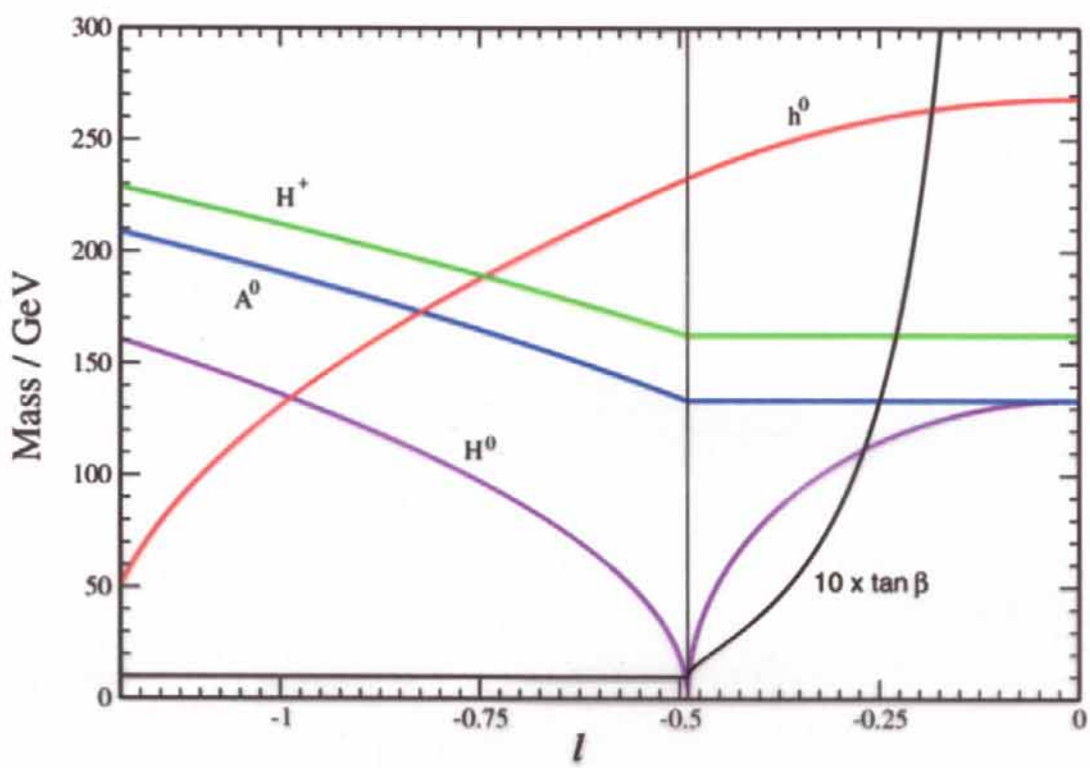
$$m_1^2 = m_2^2 = \mu^2 - \alpha_1 \tilde{m}^2 \qquad m_3^2 = 0$$

$$\lambda_1 = \lambda_2 = \frac{1}{4}(g^2+g_Y^2) + 2\alpha_1 \tilde{m}^2/M^2$$

$$\lambda_3 = \frac{1}{4}(g^2-g_Y^2) + \frac{2}{M^2}(\alpha_1 \tilde{m}^2 - e_1 \mu^2)$$

$$\lambda_4 = -\frac{1}{2}g^2 - 2\left(e_1 + 2\frac{\alpha_1^2}{\alpha_t}\right)\frac{\mu^2}{M^2}$$

$$\lambda_5 = 0 \qquad \lambda_6 = \lambda_7 = l\mu/M$$



All $m_H^2 \sim \mathcal{O}(v^2)$ (due to $m_3^2 = 0$), $m_T^2 \sim \mathcal{O}(\tilde{m}^2)$ decoupled

THE FINE-TUNING PROBLEM

MSSM :

INPUT (UV) PARAMETERS $(\mu_0, m_0, M_0, A_0, \dots)$

$$p_\alpha \rightarrow \boxed{\text{MSSM}} \rightarrow v^2 = v^2(p_1, p_2, \dots)$$

$$M_Z^2 \simeq -2.02\,\mu_0^2 + 3.57\,M_0^2 + 0.07\,m_0^2 + 0.22\,A_0^2 + 0.75\,A_0 M_0$$

↳ Natural if each term $\lesssim M_Z^2$, but this conflicts with

- Exp. lower limits on superpartner masses
- LEP bound on the Higgs mass ($m_h \gtrsim 115$ GeV)

⇩

$$m_h^2 \leq M_Z^2 c_{2\beta}^2 + \frac{3 m_t^4}{2\pi^2 v^2} \log \frac{M_{\tilde{t}}^2}{m_t^2} + \dots$$

$$m_h \geq 115 \text{ GeV} \quad \Rightarrow \quad M_{\tilde{t}} \gtrsim 3.6\, m_t$$

'M_Z REQUIRES TUNING'

Barbieri, Giudice
de Carlos, Casas
Anderson, Castaño
Chankowski et al.
Kane, King
...

QUANTIFY :

$$\frac{\delta v^2}{v^2} = \Delta_{p_\alpha} \frac{\delta p_\alpha}{p_\alpha}$$

(Δ_{μ^2} is the worst)

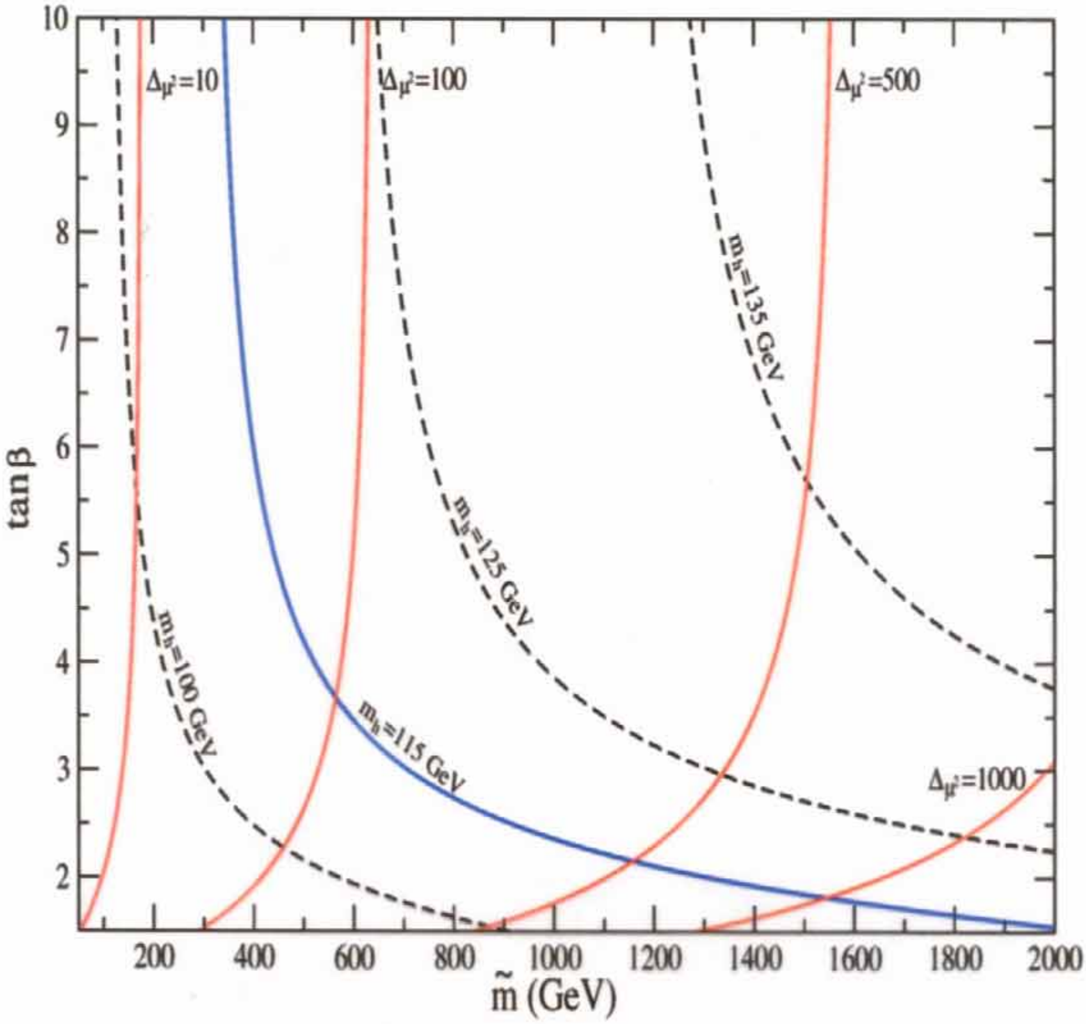
↓

accept $\Delta \lesssim 10$

$\Delta\mu^2$ in $(\tilde{m}, t_\beta)$ plane

CEH ≡ Casas, E., Hidalgo '04

$\tilde{m} = M_0 = m_0 = A_0$



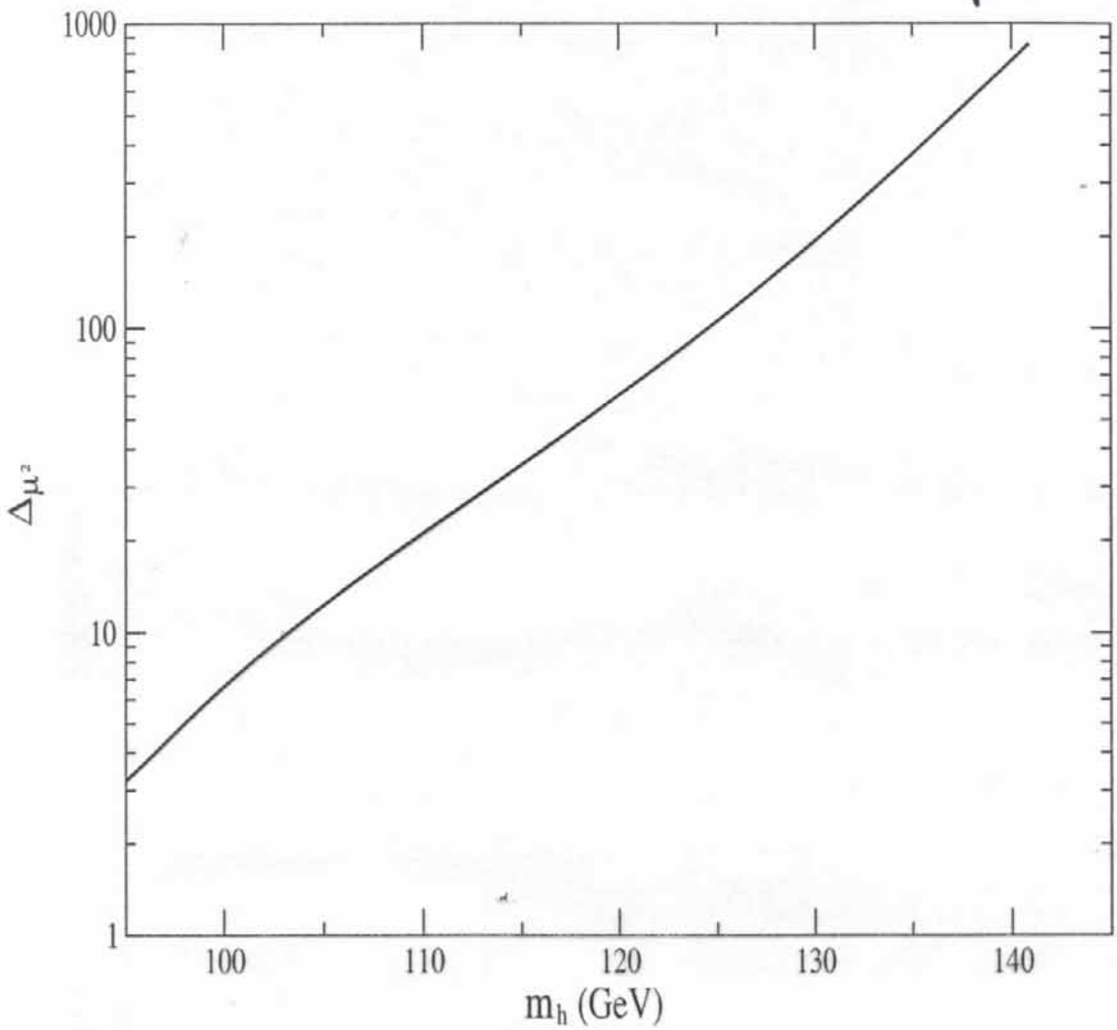
$\Delta\mu^2$ grows for $\tilde{m} \uparrow$ $t_\beta \downarrow$

$$\Delta\mu^2 < 10 \Rightarrow \begin{cases} m_h \lesssim 105 \text{ GeV} \\ \tilde{m} \lesssim 175 \text{ GeV} \end{cases}$$

$\tilde{m}^2 \sim a\omega^2 \Rightarrow \Delta \sim 20\, a$

$\Delta\mu^2$: exponentially sensitive to m_h

tanβ = 10



CEH

WHY IS THE FINE-TUNING SO LARGE ?

Write V along the breaking direction as

$$V = \frac{1}{2}\underbrace{\left(m_1^2 c_\beta^2 + m_2^2 s_\beta^2 - m_3^2 s_{2\beta}\right)}_{m^2(\beta)} v^2 + \frac{1}{4}\cdot \underbrace{\frac{1}{8}(g^2+g'^2)c_{2\beta}^2}_{\lambda(\beta)} v^4$$

$$\Downarrow$$

$$v^2 = -\frac{m^2}{\lambda}$$

LOW-SCALE $\cancel{SUSY}$

1) $\lambda \sim \frac{1}{15} c_{2\beta}^2$ SMALL!

(Improves by rad. corr.)

$\lambda = \frac{1}{15} c_{2\beta}^2 + \delta\lambda_{\cancel{SUSY}}$

CAN BE LARGER

2) $m^2 \simeq \underset{\uparrow}{3} M_0^2 - \mu_0^2$

large RG - coefficient

M not far from EW scale

RG effects small

(& not needed for EWSB)

3) $(m_h^2)_{tree} \leq M_Z^2$

$\Downarrow$

large rad. corr. needed

$\Downarrow$

larger $\tilde{m}^2$

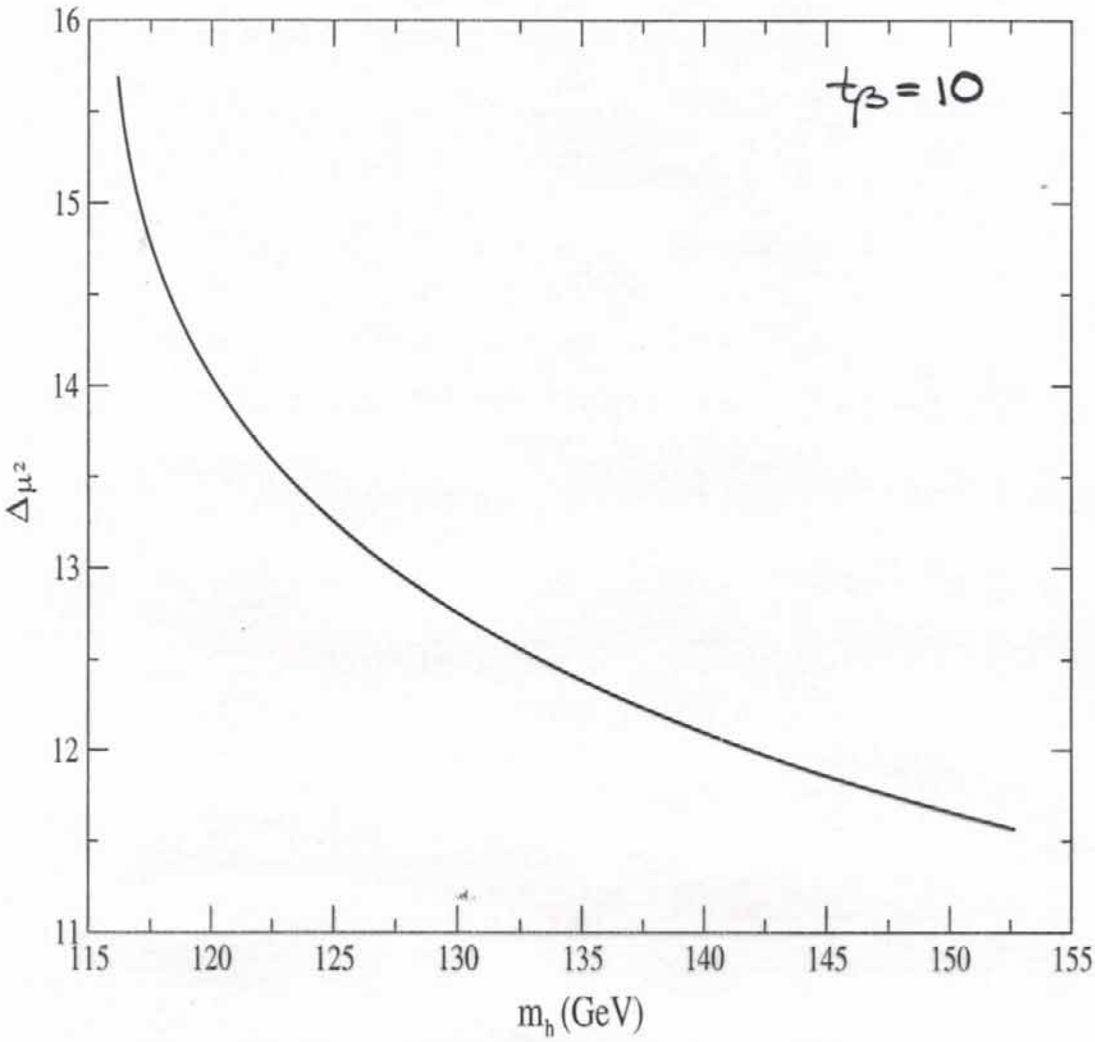
$(m_h^2)_{tree} > M_Z^2$ easily

$\Downarrow$

no need for large rad. corrections

NUMERICAL EXAMPLE: MODEL A

$$\Delta\mu^2 = \frac{-\mu^2}{\lambda v^2}\left\{1 + v^2\left[\frac{l s_{2\beta}}{2\mu M} - \frac{s_{2\beta}^2}{M^2}\left(e_1 + \frac{\alpha_1^2}{\alpha_t}\right)\right]\right\} \simeq \frac{-\mu^2}{\lambda v^2}$$



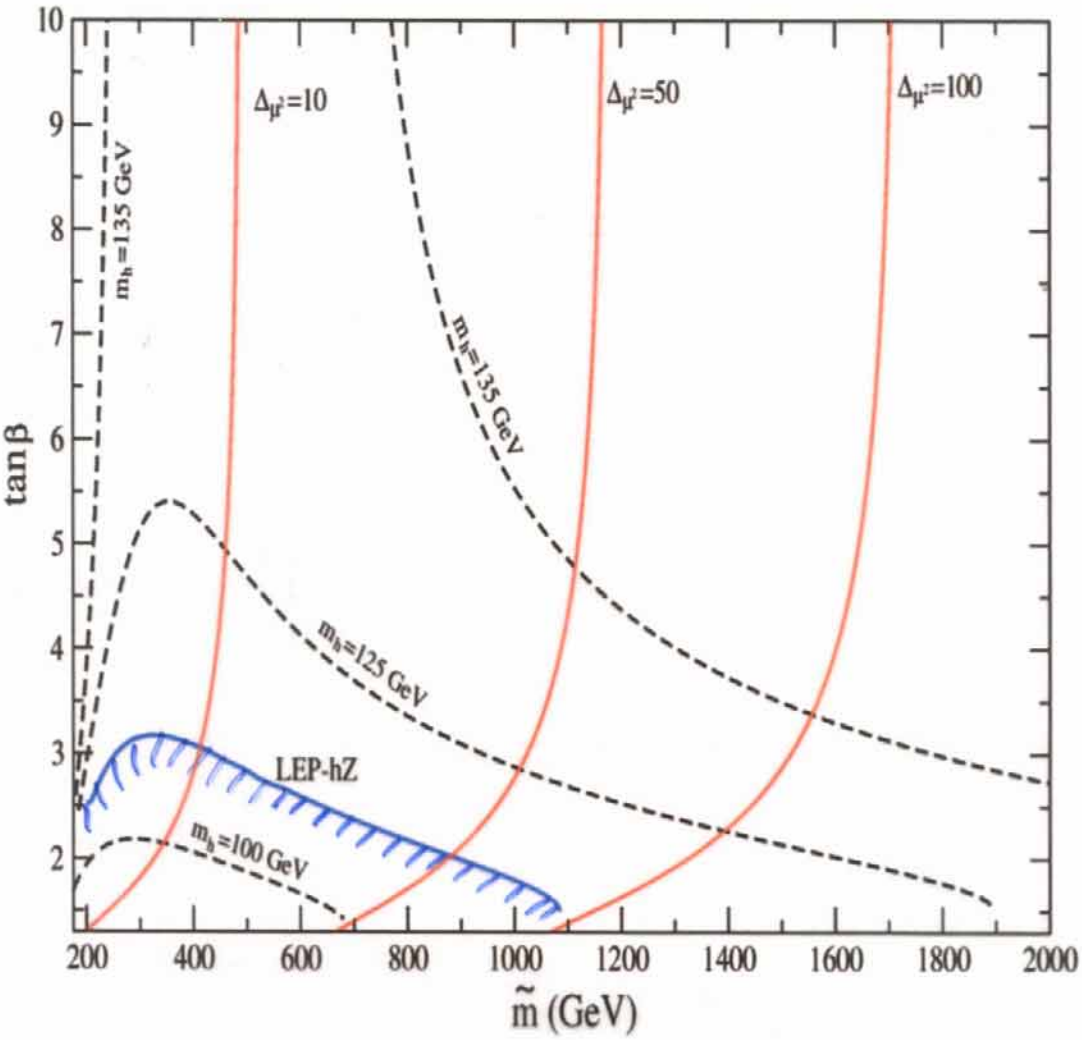
CEH

$\Delta\mu^2 \downarrow$ for $m_h \uparrow$

Compare to MSSM !

Δ_{μ^2} in $(\tilde{m}, t_\beta)$ plane

Δ_{μ^2} still grows for $\tilde{m} \uparrow$ and $t_\beta \downarrow$



But

$\Delta_{\mu^2} < 10$ $\begin{cases} \text{sets no bound on } m_h \\ \tilde{m} \lesssim 500 \text{ GeV} \end{cases}$

LHC → Finds superpartners
or
→ "LHC- fine-tuning problem"

NOVEL OPPORTUNITIES FOR EWSB FROM LOW-SCALE ~~SUSY~~

DESY, Feb '04
MORIOND, Mar '04

J.R. ESPINOSA
IFT, Madrid &
& CERN

Outline

★1. Changes in MSSM Higgs sector from low-scale ~~SUSY~~ operators

★2. The MSSM fine-tuning problem

Based on work in collaboration with A. Brignole (Padova), A. Casas, I. Hidalgo (IFT) and I. Navarro (Durham)

→ NPB 666 (2003) 105

→ JHEP 0401 (2004) 008