Higgs and SUSY Particle Predictions from SO(10) Yukawa Unification

Stuart Raby

18th International Workshop on Weak Interactions and Neutrinos

21 - 26 January 2002

Christchurch, New Zealand

In collaboration with T. Blažek and R. Dermíšek

hep-ph/0107097 and hep-ph/0201081

The Ohio State University

Outline

- Introduction to SUSY GUTs

  Gauge hierarchy problem

  EWSB $\Longleftrightarrow$ Heavy top quark

  Charge quantization

  Gauge coupling unification

- SO(10) Yukawa unification

- χ^2 analysis and predictions

  Yukawa unification is only consistent in a narrow region of SUSY parameter space with significant consequences for the Higgs and SUSY spectrum

- How robust are predictions?

- Conclusion

SUSY GUTs

- Charge quantization

— Georgi & Glashow; Pati & Salam; Georgi; Fritzsch & Minkowski

$$\mathbf{SU_5} \qquad \{Q = \begin{pmatrix} u \\ d \end{pmatrix} \;\; \bar{e} \;\; \bar{u}\} \subset \mathbf{10}$$

$$\{\bar{d} \;\; L = \begin{pmatrix} \nu \\ e \end{pmatrix}\} \subset \bar{\mathbf{5}}$$

$$H_u, \;\; H_d \subset \mathbf{5_H}, \;\; \bar{\mathbf{5}}_\mathbf{H}$$

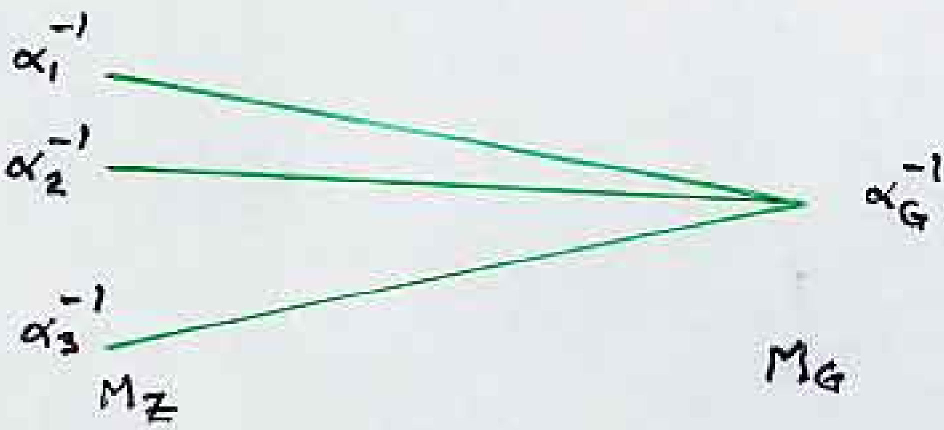
$$\mathbf{SO_{10}} \qquad \mathbf{10} + \bar{\mathbf{5}} + \bar{\nu}_{sterile} \subset \mathbf{16}$$

$$\mathbf{5_H}, \;\; \bar{\mathbf{5}}_\mathbf{H} \subset \mathbf{10_H}$$

Gauge coupling unification *

— Dimopoulos, S.R. & Wilczek; Dimopoulos & Georgi

* Only evidence for SUSY



• Significant GUT threshold corrections from Higgs and GUT breaking sectors

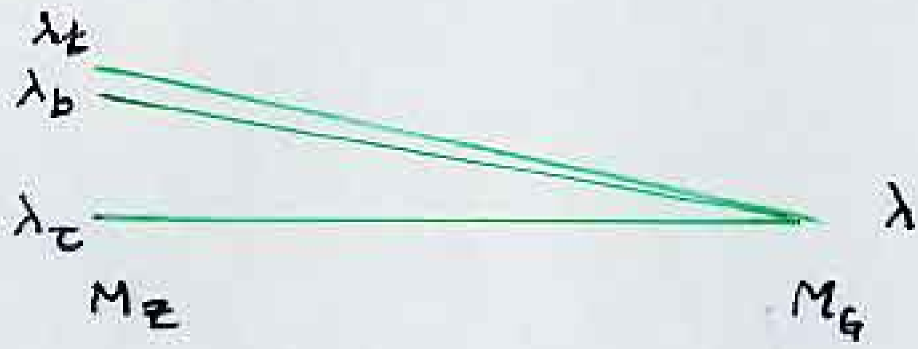
Def: $M_G \iff \alpha_1(M_G) = \alpha_2(M_G) \equiv \alpha_G$

Good fit requires: $\epsilon_3 \equiv \frac{(\alpha_3(M_G) - \alpha_G)}{\alpha_G} \sim -4\%$

SO(10) Yukawa unification

$$SO_{10} \qquad \lambda_b = \lambda_t = \lambda_\tau = \lambda_{\nu_\tau} = \lambda$$

— Banks; Olechowski & Pokorski; Ananthanarayan, Lazarides & Shafi; Dimopoulos, Hall & S.R.



$$\lambda \Leftrightarrow m_b/m_\tau \qquad m_\tau = \lambda_\tau \frac{v}{\sqrt{2}} cos\beta \Longrightarrow \tan\beta \approx 50$$

$$m_t = \lambda_t \frac{v}{\sqrt{2}} sin\beta \sim 170 \pm 20 \text{ GeV}$$

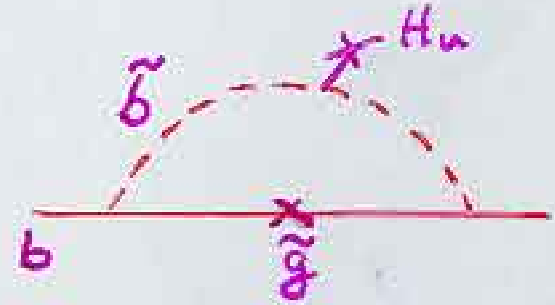
• Insignificant GUT threshold corrections from gauge and Higgs loop

Weak scale threshold corrections $\propto$ $tan\beta$

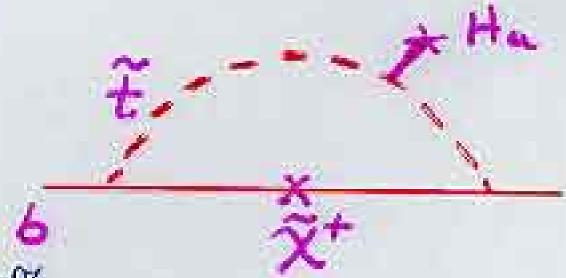
— Hall, Rattazzi, & Sarid; Carena, Olechowski, Pokorski & Wagner; Blazek, Pokorski & S.R.; Pierce, Bagger, Matchev & Zhang

$$\delta m_b/m_b = \Delta m_b^{\tilde g} + \Delta m_b^{\tilde\chi} + \Delta m_b^{\log} + \cdots$$

$$\Delta m_b^{\tilde g} \approx \frac{2\alpha_3}{3\pi} \frac{\mu m_{\tilde g}}{m_{\tilde b}^2} \underline{tan\beta}$$



$$\Delta m_b^{\tilde\chi^+} \approx \frac{\lambda_t^2}{16\pi^2} \frac{\mu A_t}{m_{\tilde t}^2} \underline{tan\beta}$$



$$\Delta m_b^{\log} \approx \frac{\alpha_3}{4\pi} \log(\frac{\tilde m^2}{M_Z^2}) \sim 6\ \%$$

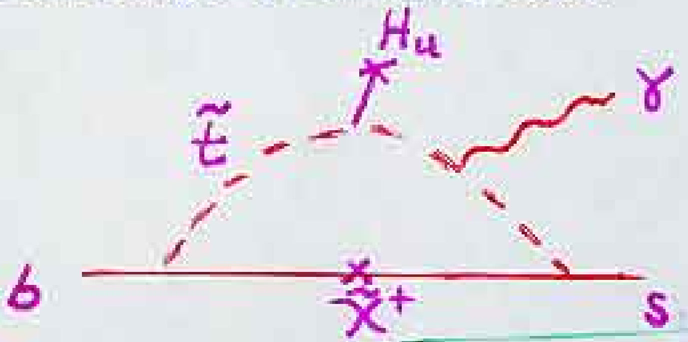
- $\Delta m_b^{\tilde g} \sim -\Delta m_b^{\tilde\chi} > 0$ for $\mu > 0$ [our conventions]

Can be ~ 50 %

- Good fits require $\delta m_b/m_b < -2\%$

Data favors $\mu > 0$

$b \to s\gamma$ — chargino term typically dominates and has opposite sign to the SM and charged Higgs contributions for $\mu > 0$, thus reducing the branching ratio.



tan β

$$\boxed{\frac{\lambda_t^2}{16\pi^2}\,\frac{\mu A_t m_b}{m_{\tilde t}^4}\,\bar{b} F_{\mu\nu}\sigma^{\mu\nu} s}$$

- $\mu < 0$ is problematic.

$$\frac{g_\mu - 2}{2} \equiv a_\mu^{NEW} = \overset{25}{\cancel{43}}\,(16) \times 10^{-10}$$

— Muon g-2 Collaboration and Brookhaven E821 Collaboration 2000

Sign of a_μ^{NEW} correlated with sign of μ

— Chattopadhyay & Nath

- Favors $\mu > 0$.

χ^2 Analysis

- 11 input parameters at M_G

$$\lambda,\ \alpha_G,\ M_G,\ \epsilon_3$$
$$m_{10},\ A_0,\ \tan\beta(M_Z)$$

D_X [D term splitting]

(or Δm_H^2 [~~Universal scalar masses~~ Just So splitting])

$m_{16},\ \mu,\ M_{1/2}$ — fixed

- 9 observables — X_i^{exp} (σ_i)

$$G_\mu,\ \alpha,\ \alpha_s(M_Z) = 0.118\ (0.002)$$
$$\rho^{NEW},\ M_Z,\ M_W$$
$$M_t = 174.3\ (5.1)$$
$$m_b(m_b) = 4.20\ (0.20),\ M_\tau$$

$$\chi^2 = \Sigma_{i=1}^{9} \frac{(X_i^{exp} - X_i^{theory})^2}{\sigma_i^2}$$

Bottom Line

- Yukawa unification possible only in a narrow region of SUSY parameter space
- Since for $\mu > 0$ need $|\Delta m_b^{\tilde\chi}| > \Delta m_b^{\tilde g}$ + ~6%

$$\Delta m_b^{\tilde g} \approx \frac{2\alpha_3}{3\pi} \frac{\mu m_{\tilde g}}{m_{\tilde b}^2} \tan\beta$$
$$\Delta m_b^{\tilde\chi^+} \approx \frac{\lambda_t^2}{16\pi^2} \frac{\mu A_t}{m_{\tilde t}^2} \tan\beta$$

- Implies

$$A_t << 0 \Longleftrightarrow A_0 << 0$$

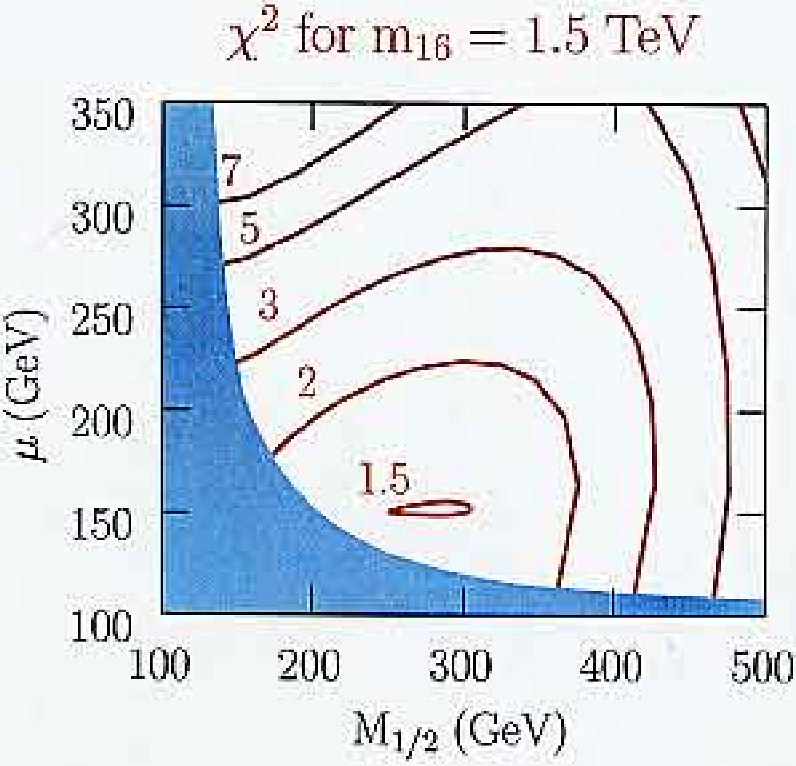
- Also $\begin{pmatrix} m_{\tilde t}^2 & m_t\, A_t \\ m_t\, A_t & m_{\tilde t}^2 \end{pmatrix}$

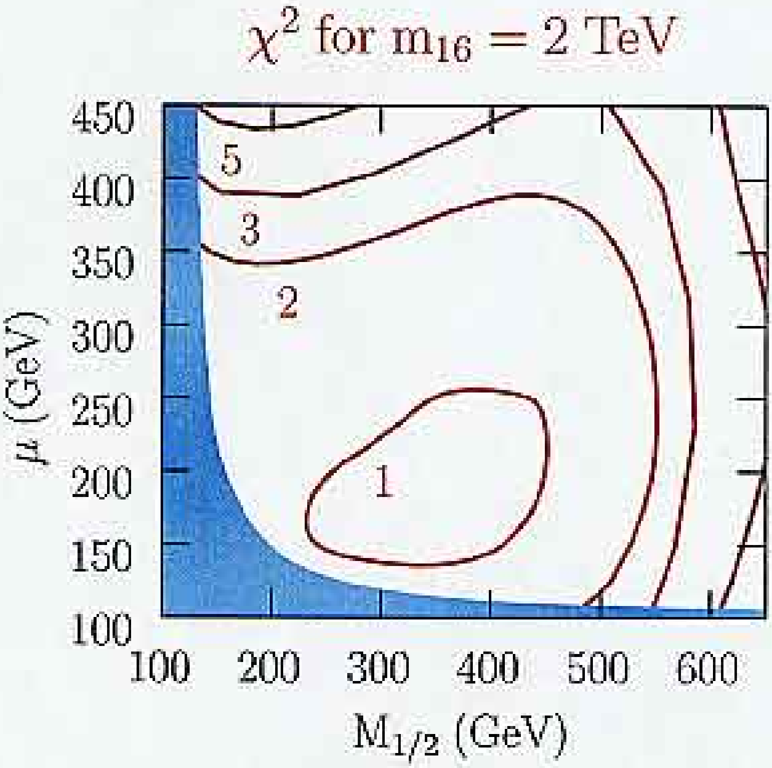
$$m_{\tilde t_1} << m_{\tilde b_1}$$

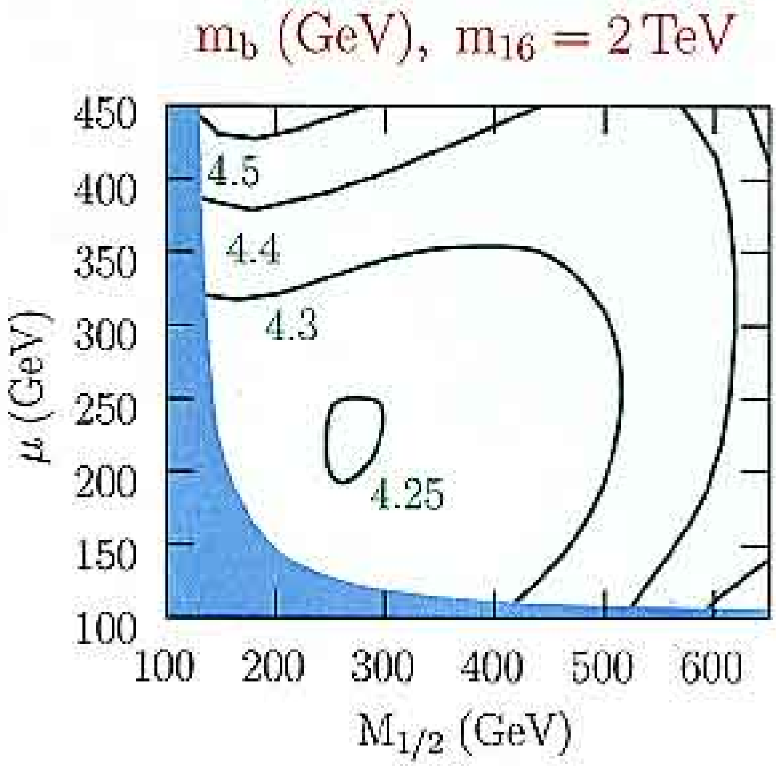
- Good fits require

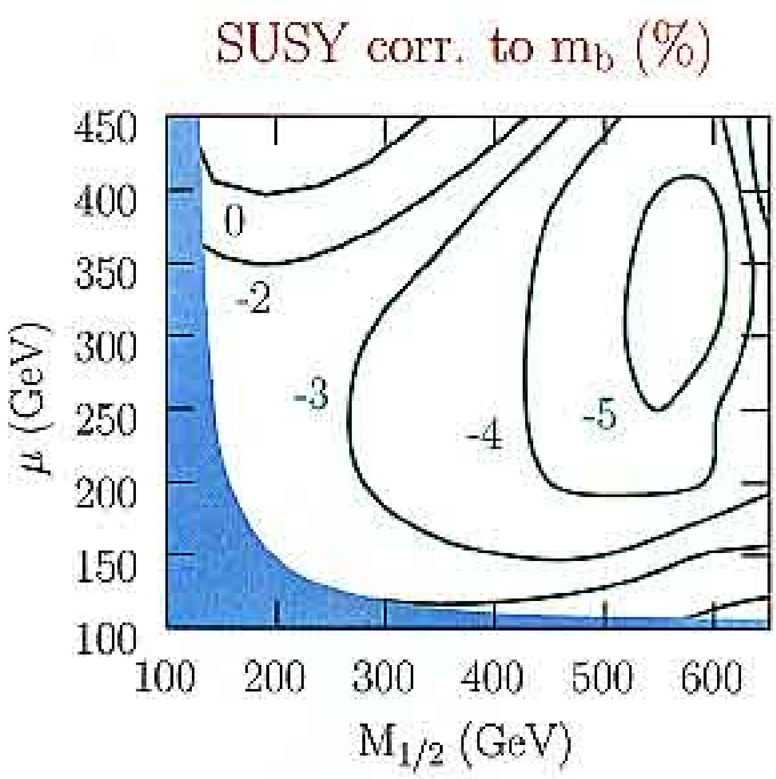
$$A_0 \sim -1.9\, m_{16}$$
$$m_{10} \sim 1.35\, m_{16}$$
$$m_{16} > 1500 \text{ GeV}$$

- Higgs splitting with ~~Universal scalar masses~~ Just So Higgs splitting

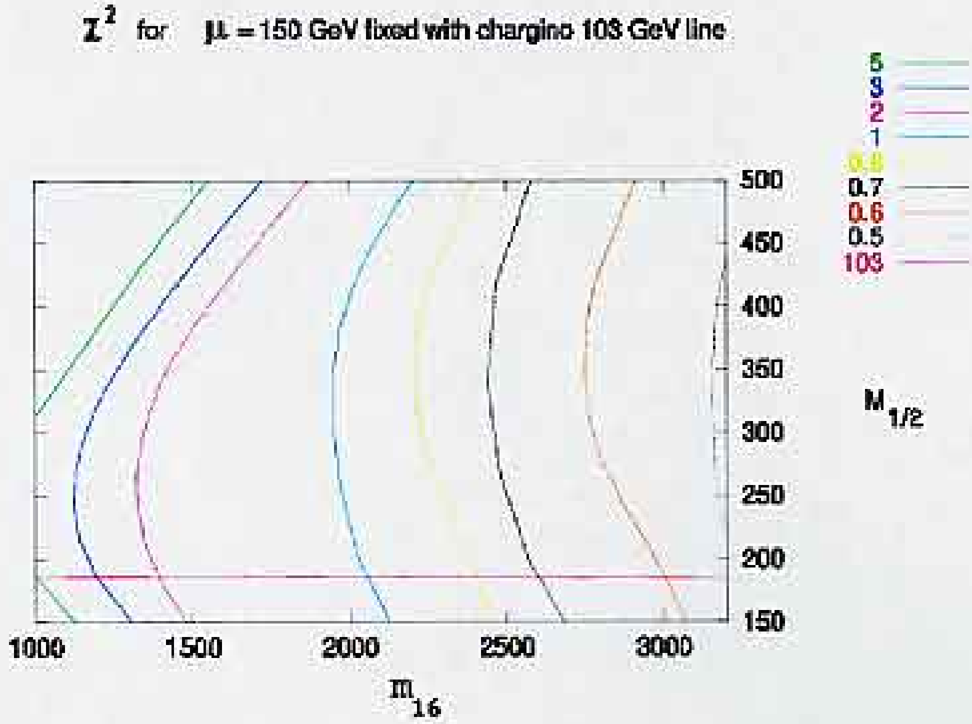

χ² for m16 = 1.5 TeV
350
300
250
200
150
100
μ (GeV)
100
200
300
400
500
M1/2 (GeV)
7
5
3
2
1.5

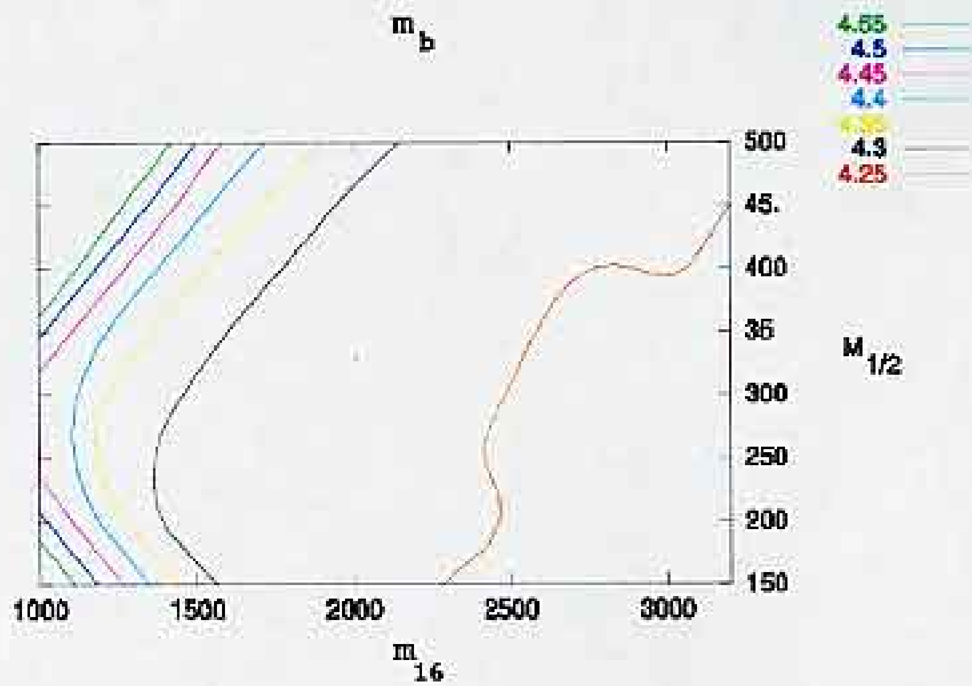

χ² for m16 = 2 TeV
450
400
350
300
250
200
150
100
μ (GeV)
100
200
300
400
500
600
M1/2 (GeV)
5
3
2
1


m_b (GeV), m_16 = 2 TeV
4.5
4.4
4.3
4.25
μ (GeV)
M_1/2 (GeV)
100
150
200
250
300
350
400
450
100
200
300
400
500
600


SUSY corr. to m_b (%)
0
-2
-3
-4
-5
μ (GeV)
M_1/2 (GeV)
100
150
200
250
300
350
400
450
100
200
300
400
500
600

$m_{16} \nearrow \quad \chi^2 \searrow$





Results — SUSY spectra for $\chi^2 \leq 1$

$$\left.\begin{aligned} \tilde{t}_1 &\sim (175 - 250)\ \text{GeV} \\ \tilde{b}_1 &\sim (500 - 650)\ \text{GeV} \\ \tilde{\tau}_1 &\sim (250 - 500)\ \text{GeV} \end{aligned}\right\} b \to s\gamma\ ?$$

$$\tilde{g} \sim (600 - 1200)\ \text{GeV}$$

$$\left.\begin{aligned} \tilde{\chi}^+ &\sim (120 - 240)\ \text{GeV} \\ \tilde{\chi}^0 &\sim (75 - 160)\ \text{GeV} \end{aligned}\right] \text{light}$$

- $\tilde{\chi}^+$ visible at Tevatron? Needs new analysis !!

New benchmark pt.

- What about $\tilde{t}_1$, $\tilde{\tau}_1$??

Constrained by $b \to s\gamma$

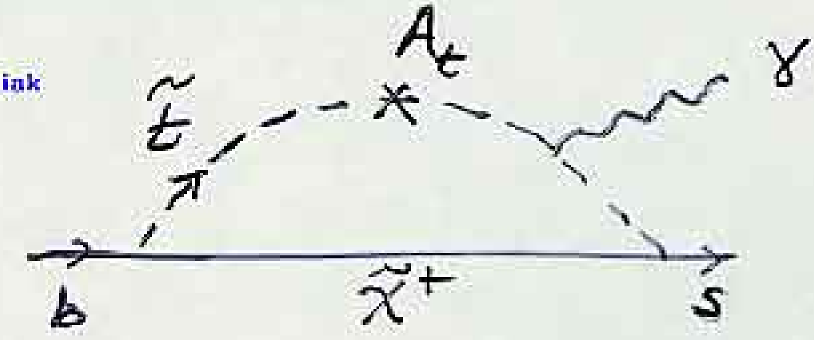
- What about Higgs — A_0, h_0, H_0, $H_\pm$??

Constrained by $B_s \to \mu^+\mu^-$

Two additional experimental constraints

$B \to s\gamma$

Gambino and Misiak

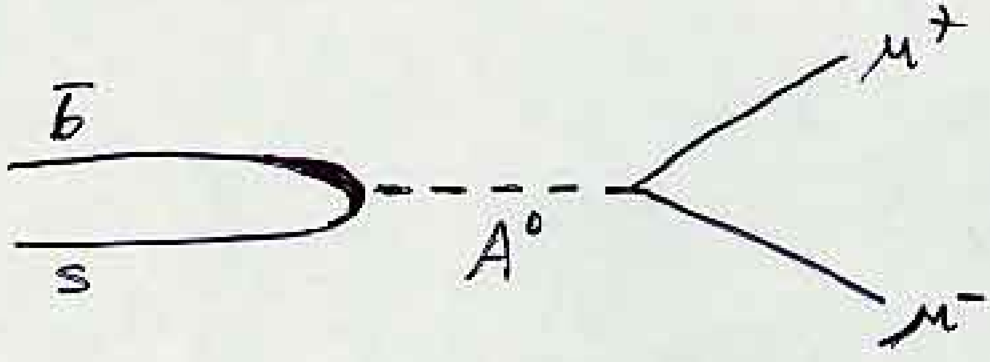


$$\sim \lambda_t^2 \frac{\mu A_t \tan\beta}{(m_{\tilde{t}_1})^4} \quad \Longrightarrow \quad m_{\tilde{t}_1} \nearrow$$

$B_s \to \mu^+\mu^-$

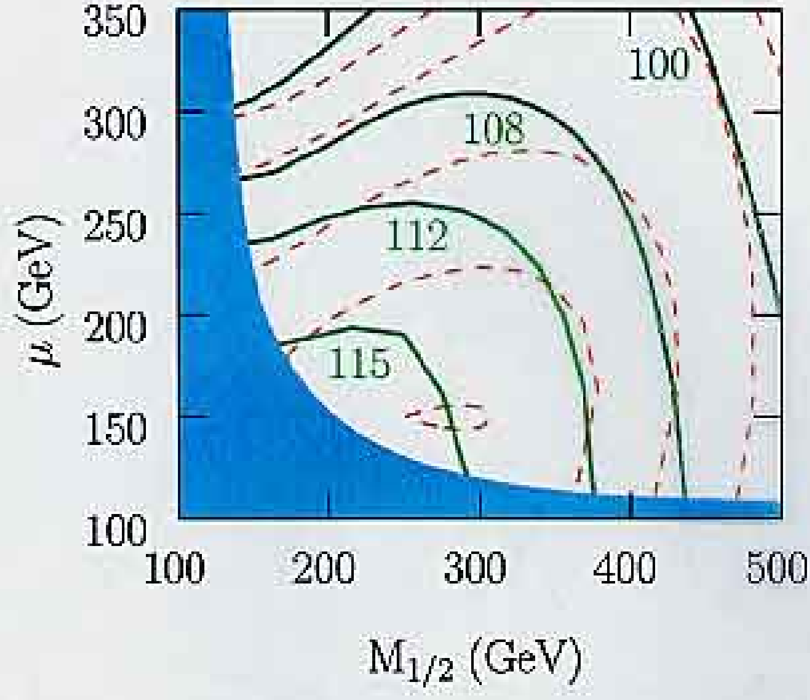
Babu and Kolda; Chankowski and Slawianowska; Bobeth et al.;

Dedes, Dreiner and Nierste; Isidori and Retico

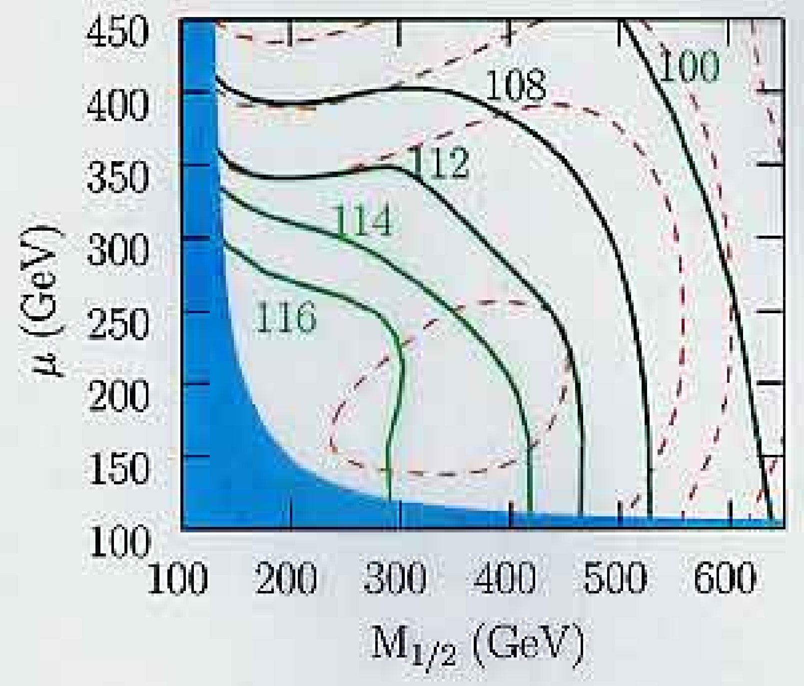


$m_{A^0} \gtrsim 200$ GeV

m_{h^0} (GeV), $m_{16} = 1.5$TeV



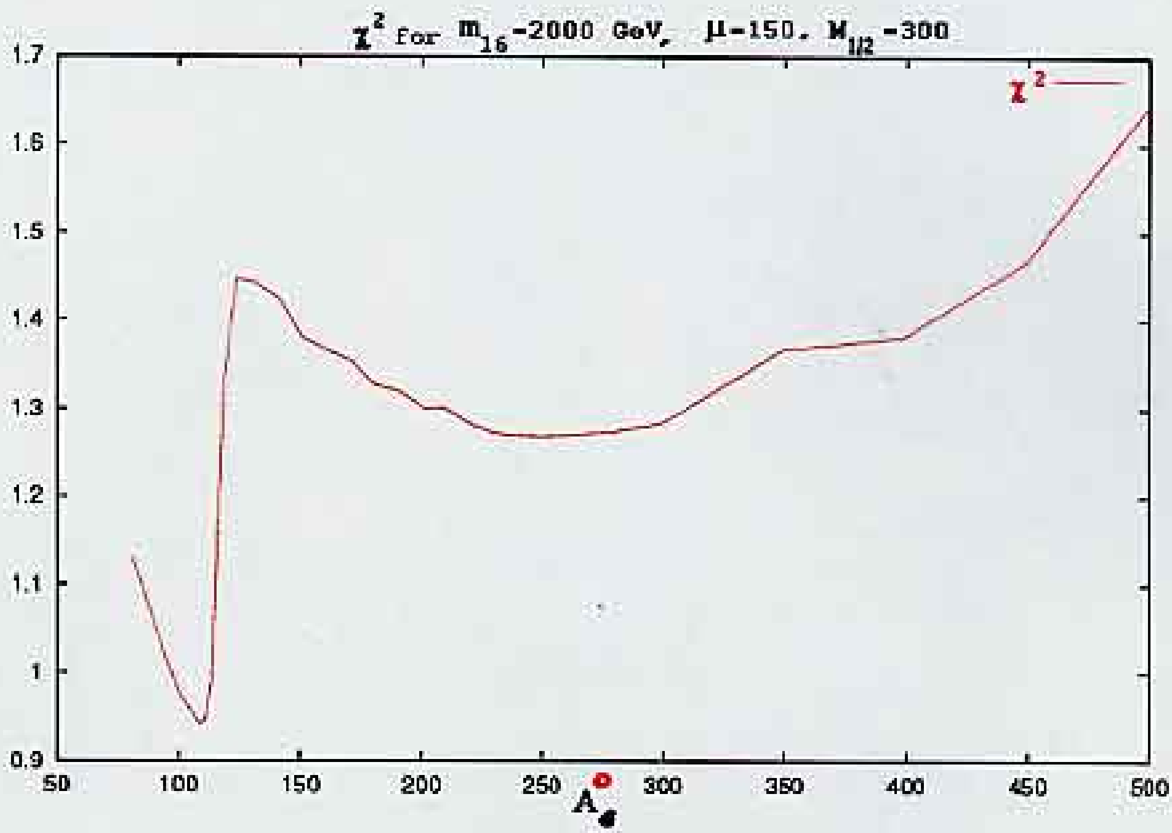
m_{h^0} (GeV), $m_{16} = 2$ TeV



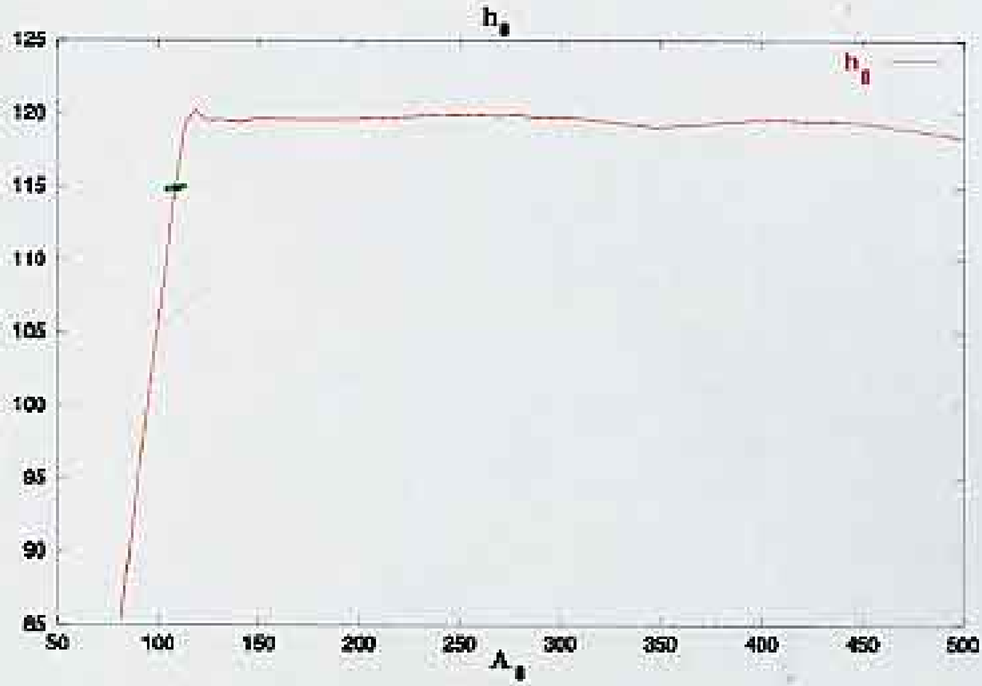
$m_{h^0} \approx 115 \pm 3 \pm 3$

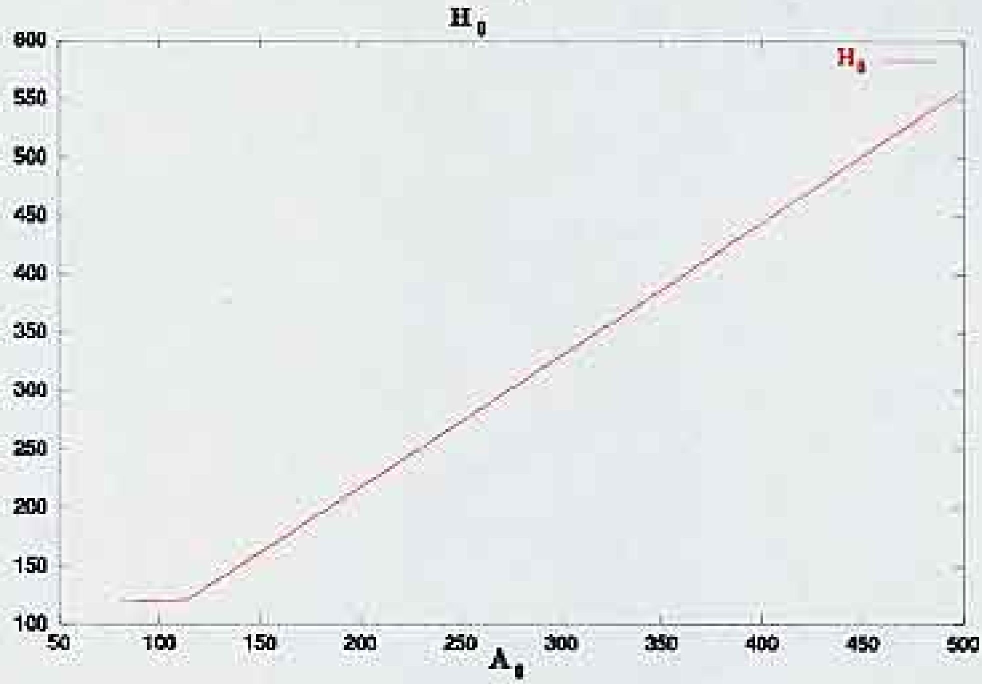
$\chi^2 \lesssim 1$ theor.

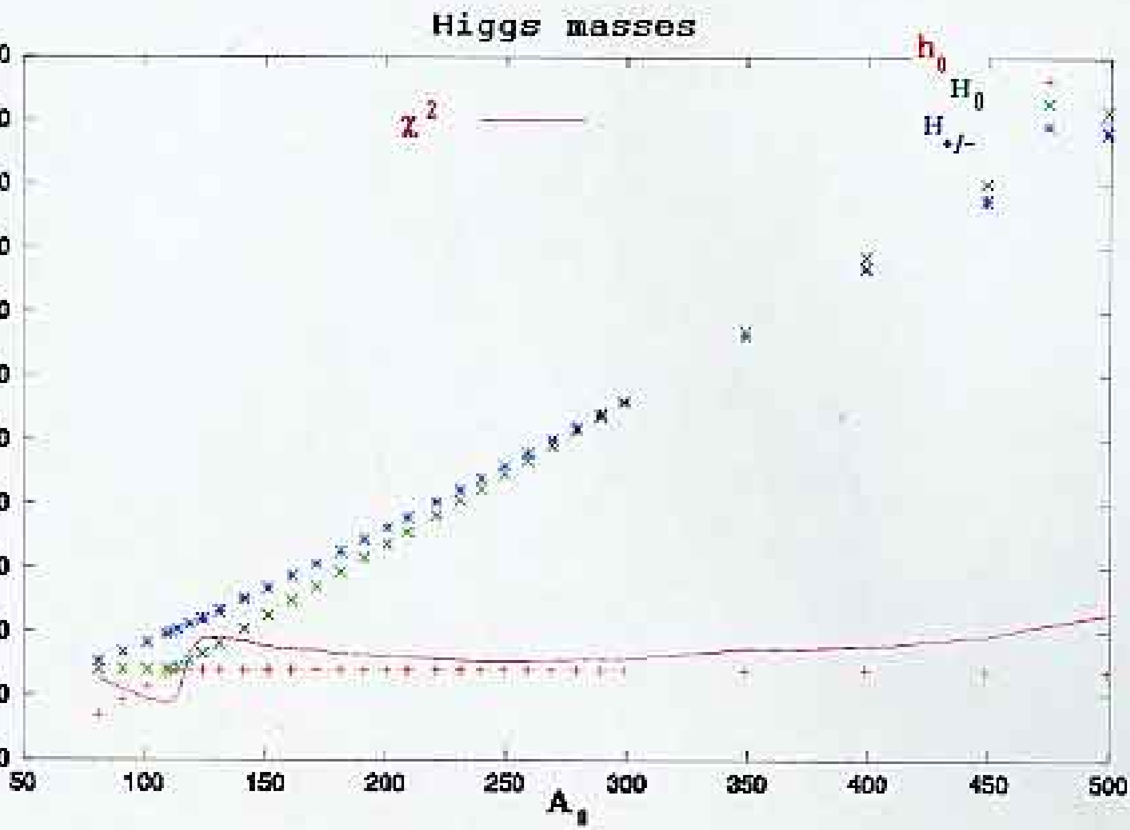
Sensitivity of χ^2 to A_0 mass



Sensitivity of Higgs masses







Higgs masses
h_0
H_0
$H_{+/-}$
χ^2
600
550
500
450
400
350
300
250
200
150
100
50
50
100
150
200
250
300
350
400
450
500
A_0

Conclusion

- $SO(10)$ Yukawa unification makes definite predictions for Higgs and Sparticle spectrum
  - $\tilde{\chi}_1^{\pm} \sim 120 - 240$ GeV Chargino visible at Tevatron ?
  - $\tilde{\chi}_1^0 \sim 75 - 160$ GeV LSP
  - $(m_{\tilde{t}_1})_{MIN} \sim 450$ GeV and $m_{\tilde{t}_1} << m_{\tilde{b}_1}$
  - $m_h \sim 114 \pm 5 \pm 3$ GeV
- Soft SUSY breaking parameters satisfy *
  - $A_0 \sim -1.9\, m_{16}$,
  - $m_{10} \sim 1.35\, m_{16}$,
  - $m_{16} > 1200$ GeV

$$\Longrightarrow a_\mu^{SUSY} < 16 \times 10^{-10}$$

* See also Bagger, Feng, Polonsky, and Zhang, *Phys. Lett.* B473, 264 (2000)

(Heavy 1st & 2nd; Light 3rd generation scalars : avoids large flavor violation)

and H. Baer and J. Ferrandis, *Phys. Rev. Lett.* 87, 211803 (2001)

- We should know soon!

EWSB with large $tan\beta$ needs
$m^2_{H_u} < m^2_{H_d}$

- D_X term vs. Just So splitting

D_X splitting — $SO(10) \to SU(5) \times U(1)_X$

$m^2_{(H_u,\, H_d)} = m^2_{10} \mp 2D_X$

$m^2_{(Q,\, \bar{u},\, \bar{e})} = m^2_{16} + D_X$

$m^2_{(\bar{d},\, L)} = m^2_{16} - 3D_X$

$\Longrightarrow\ m^2_{\tilde{b}} \leq m^2_{\tilde{t}}$ Bad

Just So splitting —

$m^2_{(H_u,\, H_d)} = m^2_{10}\,(1 \mp \Delta m^2_H)$

$m^2_{(Q,\, \bar{u},\, \bar{e})} = m^2_{16}$

$m^2_{(\bar{d},\, L)} = m^2_{16}$

$\Longrightarrow\ m^2_{\tilde{t}} << m^2_{\tilde{b}}$ Good

- Higgs special

μ term — $\mu\, H_u\, H_d$
Doublet-Triplet splitting

ν_τ contribution to Higgs splitting

Yukawa term :

$$\lambda_{\nu_\tau} \bar{\nu}_\tau L H_u + \frac{1}{2} \bar{\nu}_\tau M_{\bar{\nu}_\tau} \bar{\nu}_\tau$$

$$\lambda_{\nu_\tau} = \lambda_t = \lambda_b = \lambda_\tau \equiv \lambda$$

- ν_τ contribution distinguishes H_u and H_d
- $\Delta m^2_{H_u} \approx \frac{\lambda^2}{16\pi^2} (2m^2_{16} + m^2_{10} + A^2_0) \log(\frac{M^2_{\bar{\nu}_\tau}}{M^2_G}) + \cdots$

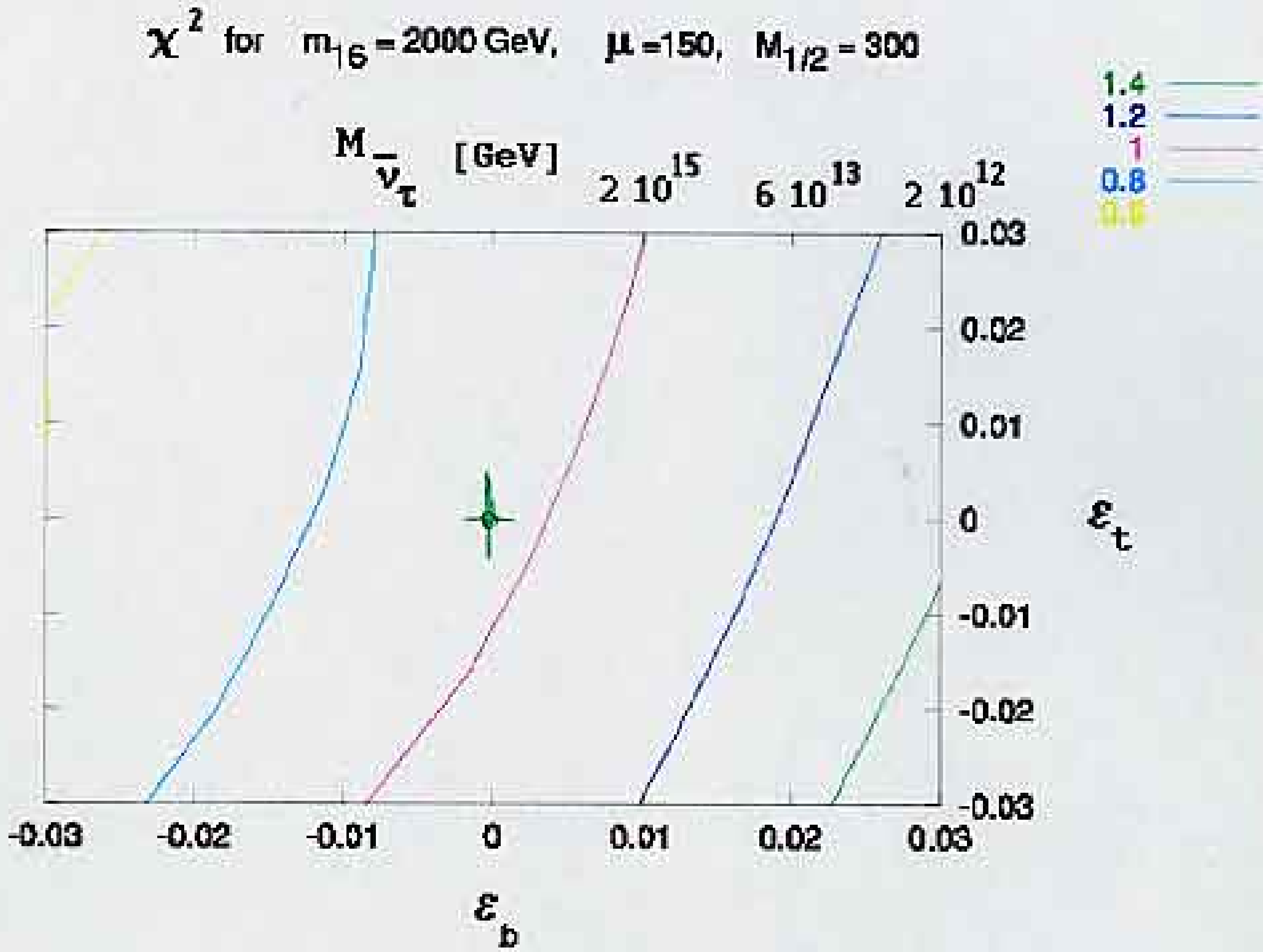
Taking typical GUT values:

$\lambda = 0.7$,
$M_{\bar{\nu}_\tau} = 10^{13}$ GeV, $M_G = 3 \times 10^{16}$ GeV ($\Longrightarrow (\Delta m^2_\nu)_{atm}$)
$A^2_0 \approx 2\, m^2_{10} \approx 4\, m^2_{16}$

$\Delta m^2_H \equiv \frac{1}{2} \Delta m^2_{H_u} / m^2_{10} = .10$

- Just So splitting of just the right size

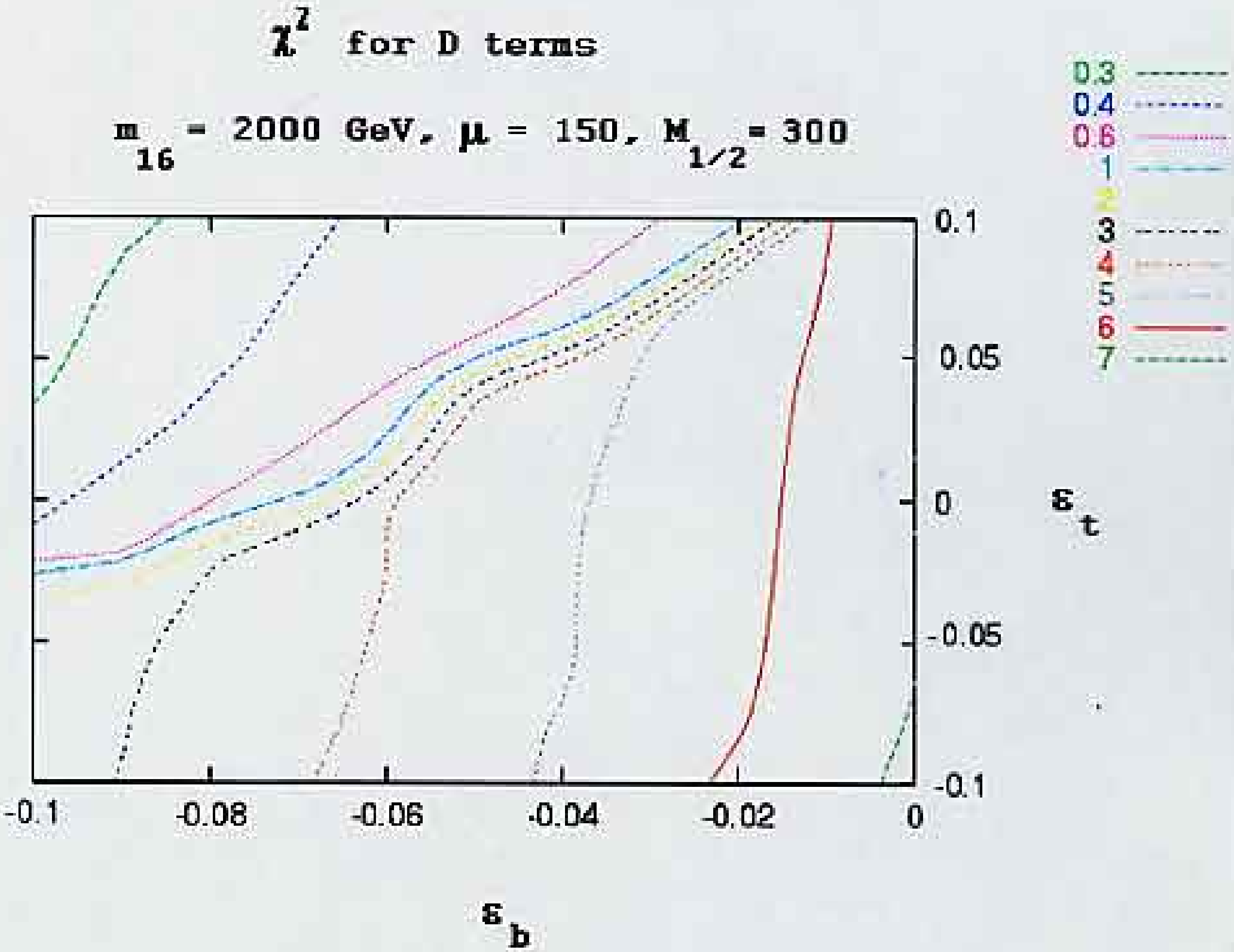
Just So Higgs splitting



$$\lambda_\tau = \lambda$$

$$\lambda_i = \lambda(1+\varepsilon_i), \quad i = b,t$$

Dx term splitting



Data points		with $B(b \to s\gamma)$ and $m_{A^0} = 200$ GeV	without
Input parameters			
α_G^{-1}		24.72	24.66
$M_G \times 10^{-16}$		3.00	3.07
ϵ_3		−0.040	−0.040
L		0.63	0.67
m_{16}		2000	2000
m_{10}/m_{16}		1.32	1.35
Δm_H^2		0.13	0.13
$M_{1/2}$		350	350
μ		200	200
$\tan\beta$		52.5	50.5
A_0/m_{16}		−1.71	−1.87
χ^2 observables	Exp (σ)		
M_Z	91.188 (0.091)	91.18	91.14
M_W	80.419 (0.080)	80.42	80.45
$G_\mu \times 10^5$	1.1664 (0.0012)	1.166	1.166
α_{EM}^{-1}	137.04 (0.14)	137.0	137.0
$\alpha_s(M_Z)$	0.118 (0.002)	0.1172	0.1176
$\rho_{new} \times 10^3$	−0.200 (1.10)	0.228	0.460
M_t	174.3 (5.1)	173.8	174.6
$m_b(m_b)$	4.20 (0.20)	4.46	4.27
M_τ	1.7770 (0.0018)	1.777	1.777
$B(b \to s\gamma) \times 10^3$	0.296 (0.035)	0.297	NA
TOTAL χ^2		2.1	0.9
h^0		118	116
H^0		217	121
A^0		200	110
H^+		229	148
$\tilde{\chi}_1^0$		130	130
$\tilde{\chi}_2^0$		190	190
$\tilde{\chi}_1^+$		178	178
$\tilde{g}$		909	913
$\tilde{t}_1$		509 (−30)	222
$\tilde{b}_1$		749 (−42)	588
$\tilde{\tau}_1$		459 (+47)	420
$a_\mu^{SUSY} \times 10^{10}$	25.6 (16)	5.8	5.5