Pinning Down the MSSM Higgs Sector at a Linear Collider for Large or Small Phases

S. Mrenna* **(M. Carena, H. Haber, H. Logan)**
(C. Wagner, A. Pilaftsis)

* *UC Davis Institute for High Energy Physics*

- ☆ Educated sampling of MSSM parameter space
- ☆ No specific High-Energy Framework
- ☆ Real or Complex SUSY-breaking parameters
  - includes explicit CP violation
- ☆ CPHDecay V1.0
  - All present knowledge of radiative corrections to masses and couplings (CPH)
- ☆ When can we distinguish the MSSM from SM?
- ☆ When can we resolve different MSSMs?

Talk available at:

`http://moose.ucdavis.edu/mrenna/talks/LChiggs.ps`

See related talk by Heather Logan

Main MSSM parameter dependence

for $[m_A, \tan\beta]$

- $M_S^2 = \frac{1}{2}(M_{\tilde{t}_1}^2 + M_{\tilde{t}_2}^2) \quad \log(M_S^2/m_t^2)$
- $\tilde{A}_t = A_t - \mu^*/\tan\beta \quad \tilde{A}_b = A_b - \mu^* \tan\beta$
  - ▷ $\tilde{A}_t = 0 \Rightarrow$ Minimal Mixing
  - ▷ $\tilde{A}_t = \sqrt{6} M_S \Rightarrow$ Maximal Mixing ($\mu \simeq -0.2$ TeV)
- $M_{\tilde{g}}$
  - ▷ 2-loop in masses, 1-loop in Yukawas
- Phases of $A_t, A_b, \mu, M_{\tilde{g}}$
  - ▷ At tree level, all CP violating phases can be rotated away
  - ▷ No longer true at the loop level
    - ✔ Im$(\mu m_{12}^{*} A_t)$ or Im$(\mu m_{12}^{*} M_{\tilde{g}}) \neq 0$
  - ▷ CP labels on Higgs mass eigenstates are not absolute
    - ✘ $h, H, A \to H_1, H_2, H_3$
  - ▷ $M_A \to M_{H^\pm}$

SUSY-breaking effects

- u and d labels on H_u, H_d are not absolute

$$\mathcal{L}_{\rm eff} \simeq (h_b + \delta h_b) H_d^0 b\bar{b} + \Delta h_b H_u^0 b\bar{b}$$

$$\begin{aligned} m_b &= (h_b + \delta h_b)\langle H_d^0 \rangle + \Delta h_b \langle H_u^0 \rangle \\ &= h_b v_d (1 + \frac{\delta h_b}{h_b} + \frac{\Delta h_b}{h_b} \tan\beta) \simeq h_b v_d (1 + \Delta(m_b)) \end{aligned}$$

$$\begin{aligned} \Delta(m_b) \simeq \frac{2\alpha_3}{3\pi} \tan\beta \frac{M_{\tilde{g}}\, \mu}{\max(M_{\tilde{b}_2}^2, M_{\tilde{g}}^2)} \\ + \frac{Y_t}{4\pi} \tan\beta \frac{A_t\, \mu}{\max(M_{\tilde{t}_2}^2, \mu^2)} \end{aligned}$$

- modifies H_i couplings to d–type fermions

$$g_{hb\bar{b}} \simeq -\frac{m_b \sin\alpha}{v\cos\beta} \frac{1}{1+\Delta(m_b)} \left[1 - \frac{\Delta(m_b)}{\tan\alpha \tan\beta} \right]$$

- $g_{hb\bar{b}}$ coupling suppression for $\Delta(m_b) = \tan\alpha\tan\beta$

✘

$$g_{h\tau\tau} \simeq -\frac{m_\tau \cos\alpha}{v\sin\beta} \Delta(m_b) \neq 0$$

✘ $\sin\alpha \to 0$, $g_{hb\bar{b}} \propto \Delta(m_b)$

Extraction of $\Delta(m_b)$ from LC Data

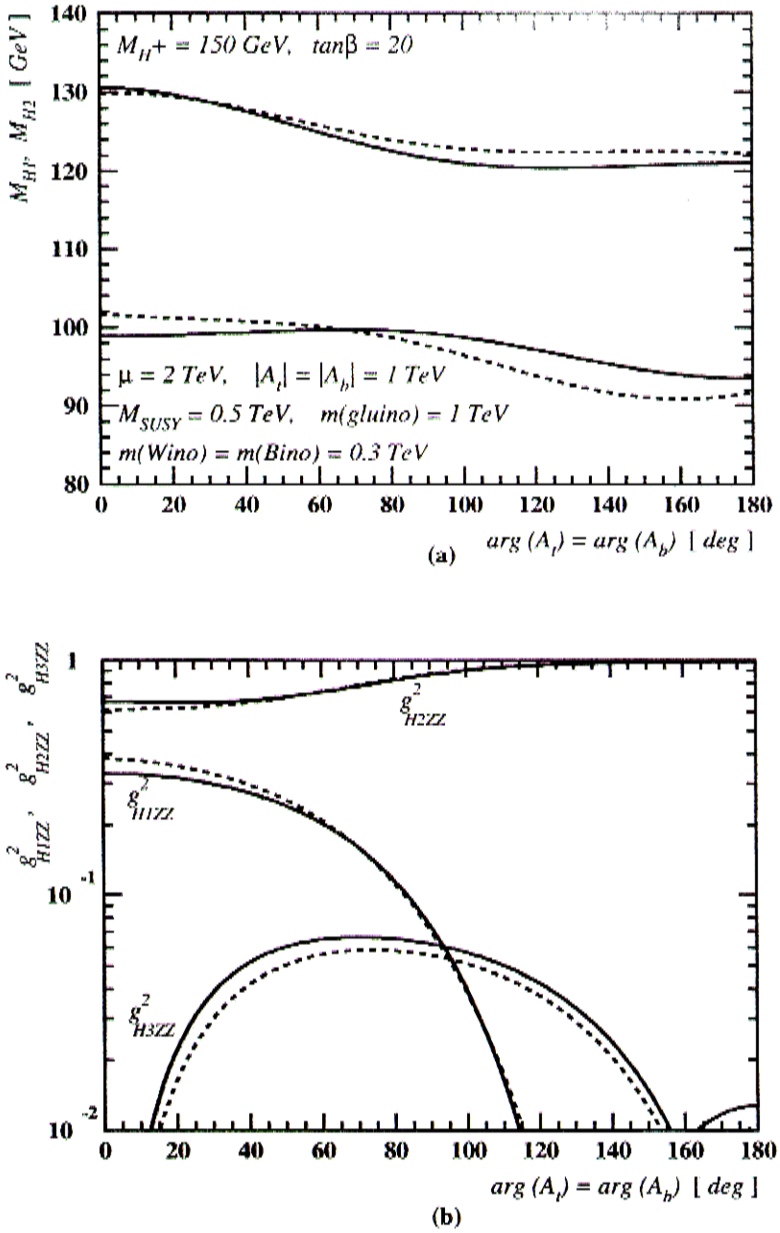
$\widehat{\ } \equiv$ ratio with Standard Model Value

$$\frac{\widehat{BR(b)}}{BR(\tau)} = \left(\frac{1}{1+\Delta(m_b)} \left[1 + \Delta(m_b) \sqrt{\frac{\widehat{BR(c)}}{BR(\tau)}} \right] \right)^2$$

$$\Rightarrow \Delta(m_b) = \frac{1-\sqrt{x}}{\sqrt{x}-\sqrt{y}}$$

$$x = \frac{\widehat{BR(b)}}{BR(\tau)}, y = \frac{\widehat{BR(c)}}{BR(\tau)}$$

other information is needed to extract soft SUSY-breaking parameters



Solid = Arg(gluino) = 0 Dashed = Arg(gluino) = $\pi/2$

Phases complicate SUSY phenomenology

(See Gunion, et al, for sum rules between couplings in generic 2HDM)

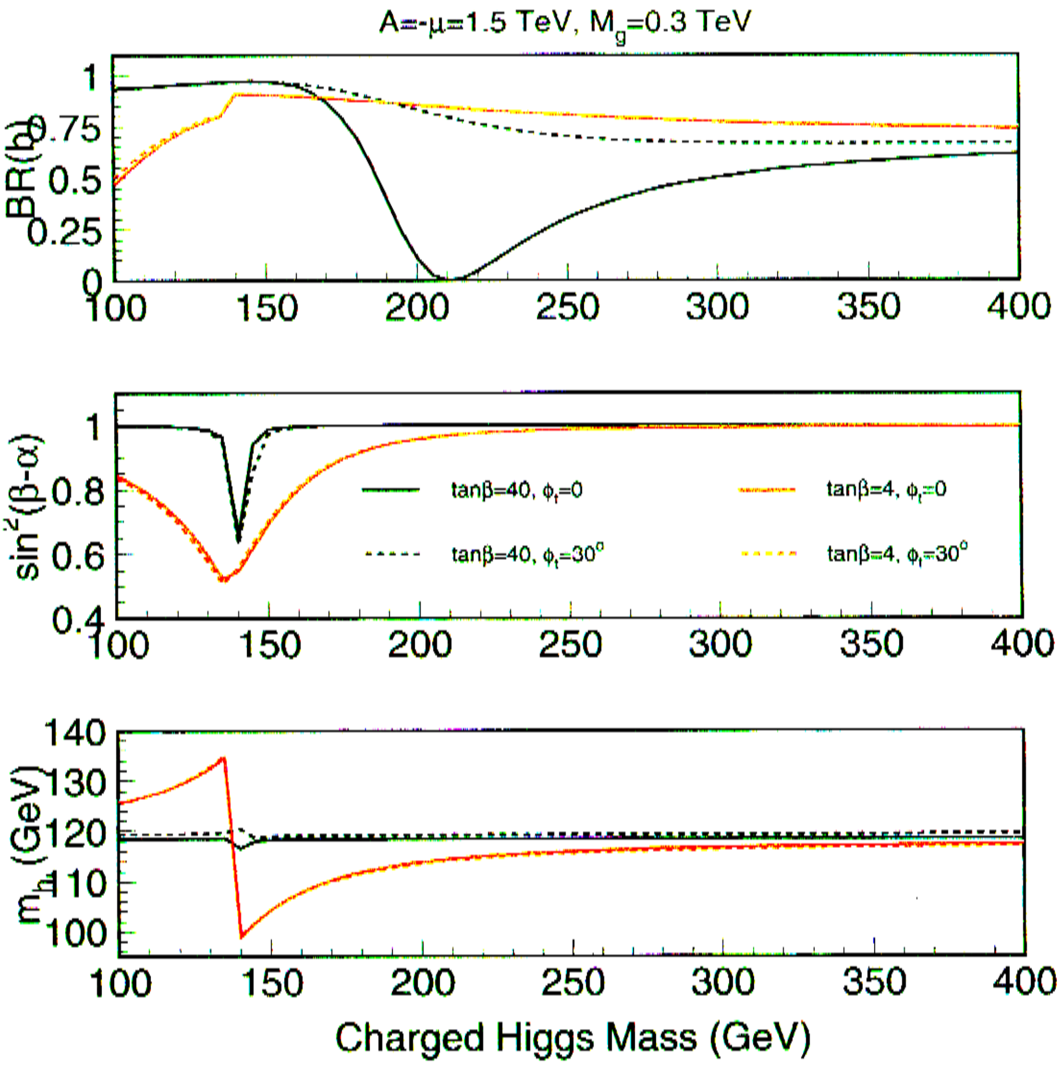
- Higgs mass eigenstates H_1, H_2, H_3 have a mixture of CP-even and CP-odd couplings
- Higgs coupling to W, Z shared by all three Higgses
  - ▷ $\sin(\alpha - \beta) = \cos\beta \sin\alpha - \sin\beta\cos\alpha \Rightarrow$
    $g_{H_i VV} = \cos\beta O_{1i} + \sin\beta O_{2i}$
  - ▷ $g^2_{H_i VV} = 1$
- $|A_t - \mu^* / \tan\beta|$ dependence of masses and mixing

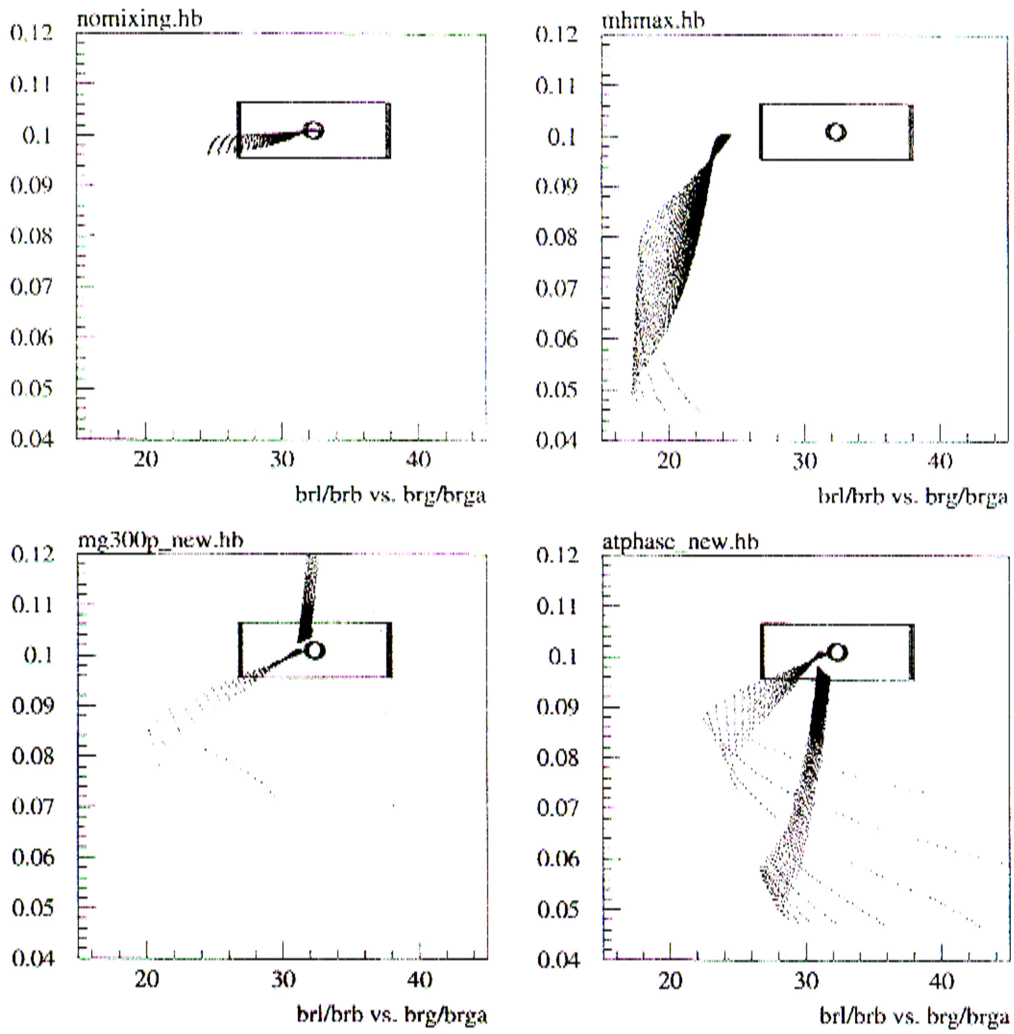
✘ Light Higgses may have meager couplings to W, Z

- Light Higgses can elude detection at LEP
- Challenging for Tevatron

✔ CPHDecay V1.0

- ▷ Effective Potential Calculation of Carena, Ellis, Pilaftsis, Wagner
- ▷ Γ_i Calculation (including $\Delta(m_b)$ and $\Delta(m_t)$) $\cdots$ [see related Γ_i calc of Choi, Lee]
- ▷ Sfermion loops being debugged ($H_i \to \gamma\gamma, gg$)

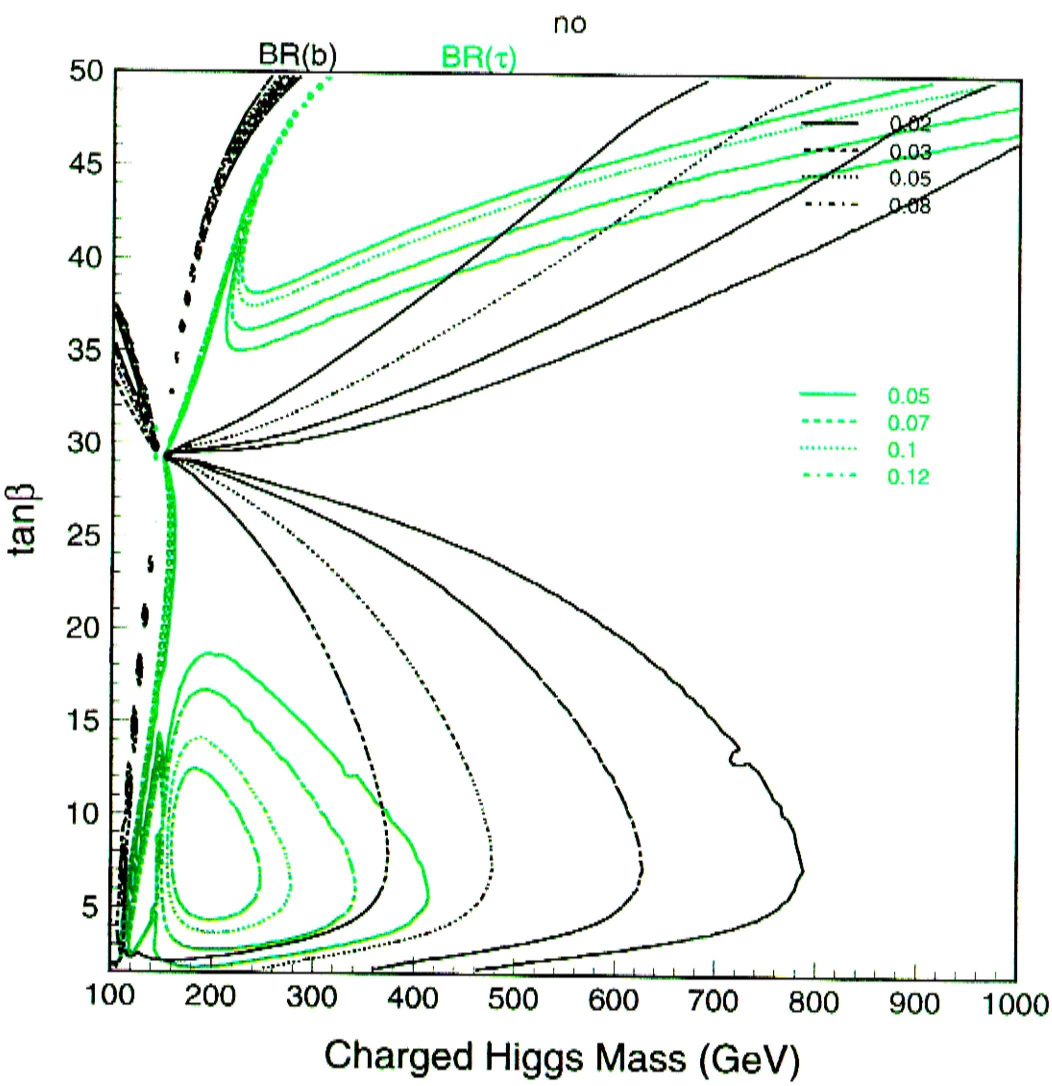

A=-μ=1.5 TeV, M_g=0.3 TeV
BR(b)
1
0.75
0.5
0.25
0
100
150
200
250
300
350
400
sin²(β-α)
1
0.8
0.6
0.4
tanβ=40, φ_t=0
tanβ=4, φ_t=0
tanβ=40, φ_t=30°
tanβ=4, φ_t=30°
m_h (GeV)
140
130
120
110
100
Charged Higgs Mass (GeV)

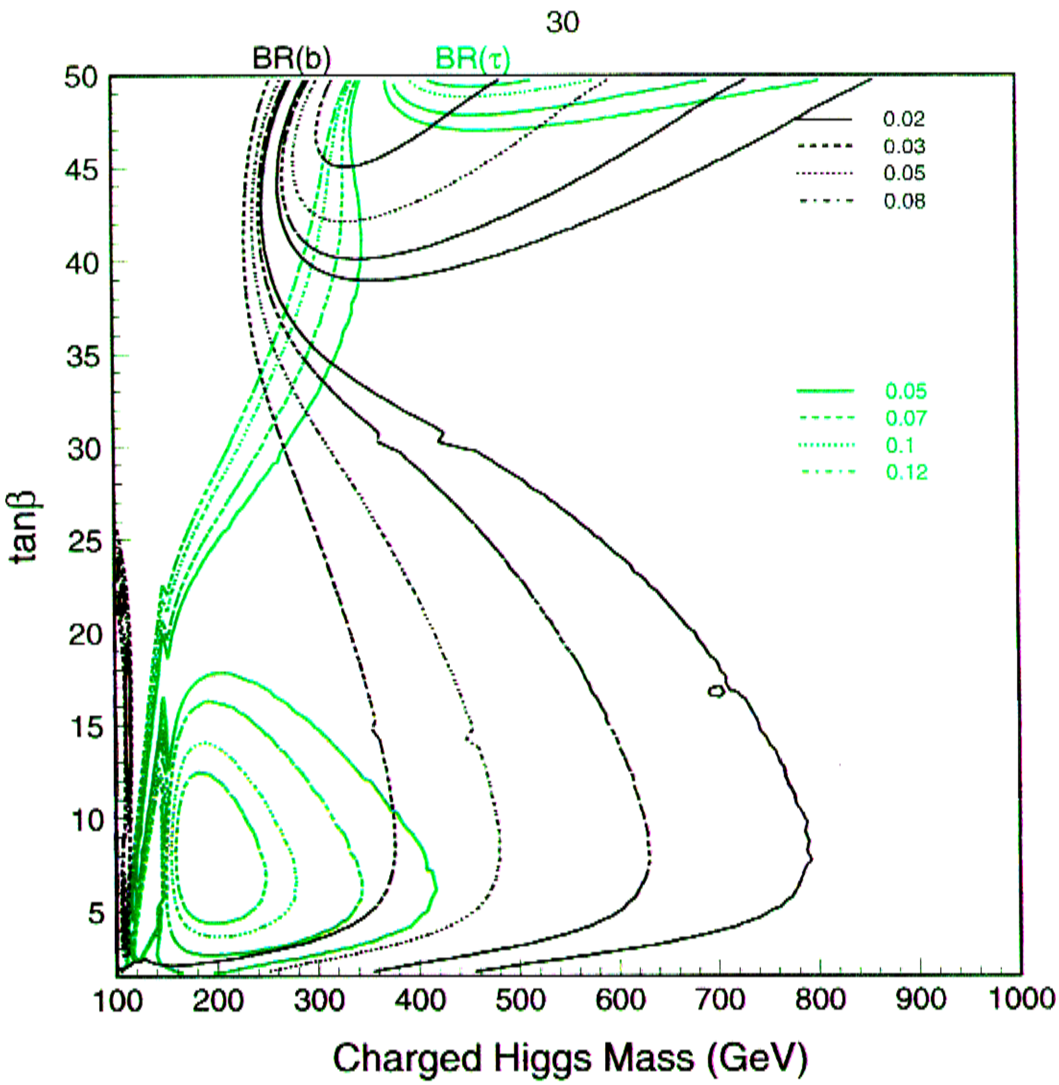


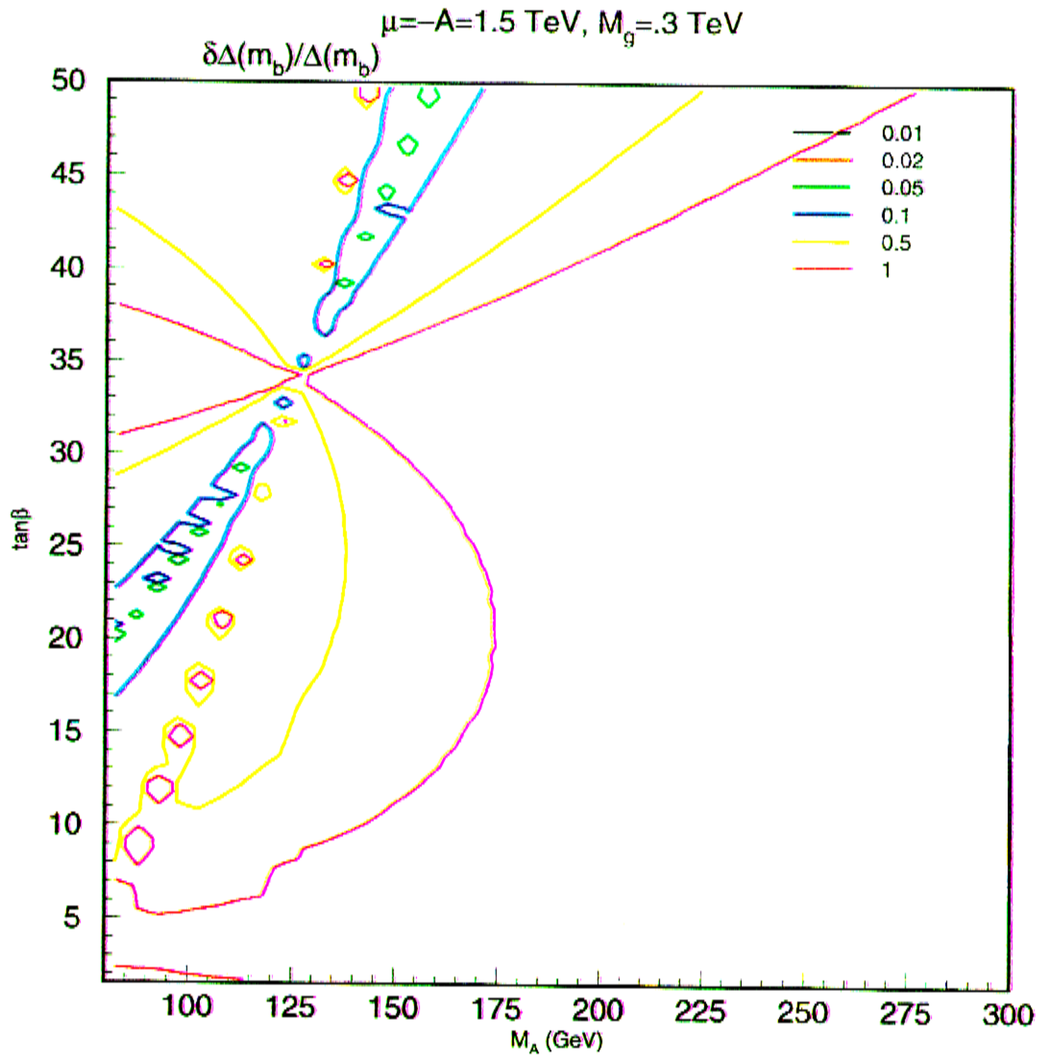
Correlations between $BR(\tau)/BR(b)$ and $BR(g)/BR(\gamma)$

118 GeV $<$ SM-like Higgs boson mass $<$ 121 GeV

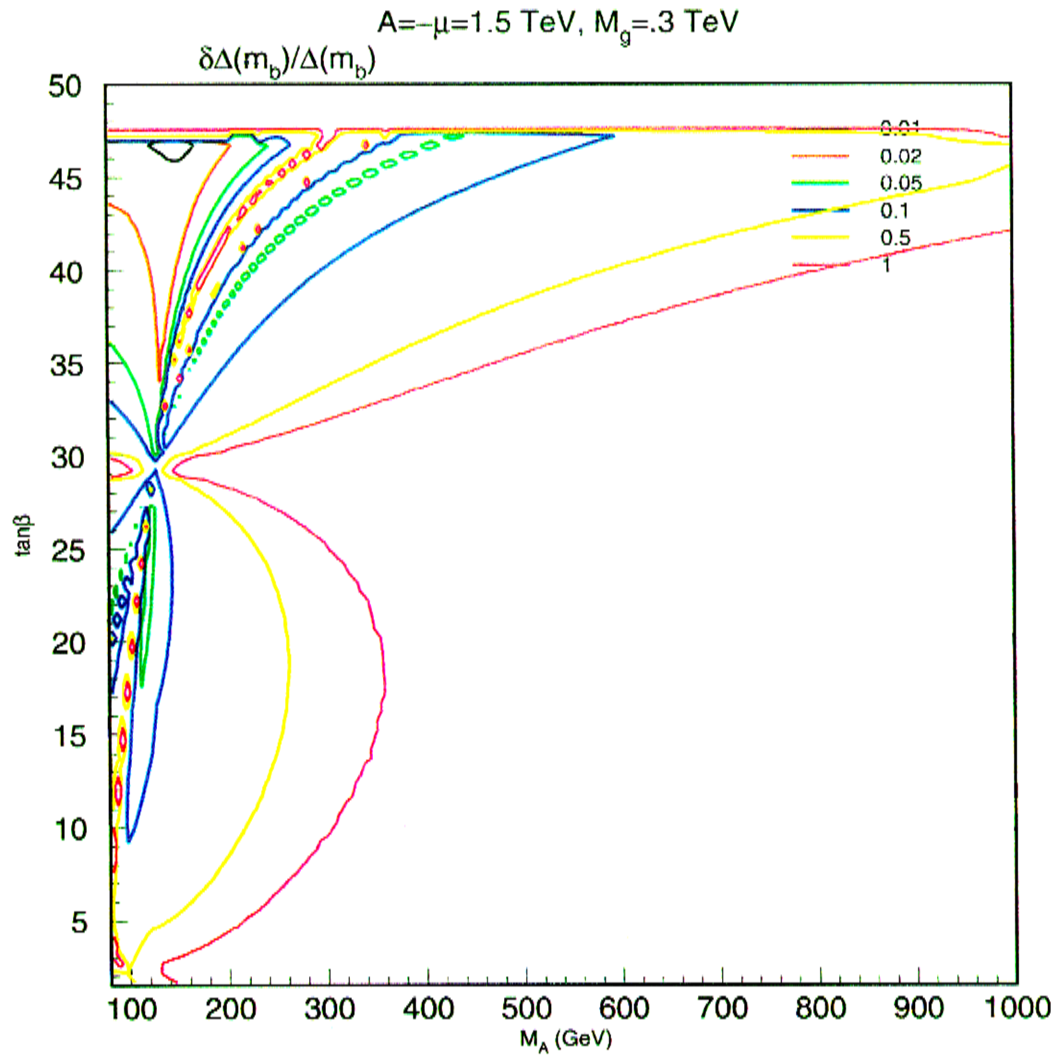
Im(A_t) dependence


no
BR(b)
BR(τ)
0.02
0.03
0.05
0.08
0.05
0.07
0.1
0.12
tanβ
50
45
40
35
30
25
20
15
10
5
100
200
300
400
500
600
700
800
900
1000
Charged Higgs Mass (GeV)


30
BR(b)
BR(τ)
0.02
0.03
0.05
0.08
0.05
0.07
0.1
0.12
tanβ
50
45
40
35
30
25
20
15
10
5
100
200
300
400
500
600
700
800
900
1000
Charged Higgs Mass (GeV)



μ=−A=1.5 TeV, M_g=.3 TeV
δΔ(m_b)/Δ(m_b)
0.01
0.02
0.05
0.1
0.5
1
tanβ
50
45
40
35
30
25
20
15
10
5
100
125
150
175
200
225
250
275
300
M_A (GeV)


A=−μ=1.5 TeV, M_g=.3 TeV
δΔ(m_b)/Δ(m_b)
tanβ
M_A (GeV)
0.01
0.02
0.05
0.1
0.5
1
50
45
40
35
30
25
20
15
10
5
100
200
300
400
500
600
700
800
900
1000