$\tan\beta$ from Heavy Higgs Boson Production at Linear Colliders*

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I. Introduction: $\tan\beta$ in MSSM

II. $H(A)b\bar{b}$, $H(A)t\bar{t}$ production at LC
(versus $\tan\beta$)

III. Sensitivity on probing $\tan\beta$
(from cross section measurements)

IV. Conclusions

*Barger, Han, Jiang: hep-ph/0006223.

I. Introduction: $\tan\beta$ in MSSM

A. An important SUSY parameter:

$$\tan\beta = \frac{v_2}{v_1} = \frac{< H_2 >}{< H_1 >}$$

Because:

- characterizes EWSB;
- enters particle mass relations;
- determines particle interactions;
- distinguishes GUTs scenarios:
  $b-\tau$; Yukawa unification; large m_t...

Crucial to experimentally determine $\tan\beta$!

B. Many ways to probe $\tan\beta$:

- m_h: LEP2 $\Rightarrow \tan\beta > 2$;
- $t \to bH^+$: Tevatron $\Rightarrow \tan\beta < 80$;
- $e^+e^- \to \chi^+\chi^-$ for low $\tan\beta$[†]
- $\tilde{\tau}_L - \tilde{\tau}_R$: mixing[‡]
- $H, A \to t\bar{t}, \tau\bar{\tau}$: at LHC[§]
- Kinematics from $\chi^{\pm,0}, \tilde{\ell}$ decays at LHC[¶]

[†] Feng, Murayama, Peskin, Tata

[‡] Nojiri, Fujii, Tsukamoto

[§] Plehn, Rainwater, Zeppenfeld

[¶] Denegri, Majerotto, Rurua; Hinchliffe, Paige

II. $H(A)b\bar{b}$, $H(A)t\bar{t}$ production at LC (versus $\tan\beta$)

A. Higgs couplings to heavy quarks:

$$A\bar{t}t: \quad \frac{-gm_t}{2m_W}\cot\beta\,\gamma_5 \qquad A\bar{b}b: \quad \frac{-gm_b}{2m_W}\tan\beta\,\gamma_5$$

$$H\bar{t}t: \quad \approx \frac{igm_t}{2m_W}\cot\beta \qquad H\bar{b}b: \quad \approx \frac{-igm_b}{2m_W}\tan\beta$$

$$H^+\bar{t}b: \quad \frac{igV_{td}}{2\sqrt{2}m_W}[(m_b\tan\beta + m_t\cot\beta) + (m_b\tan\beta - m_t\cot\beta)\gamma_5]$$

$\Rightarrow$ most direct probe to $\tan\beta$.

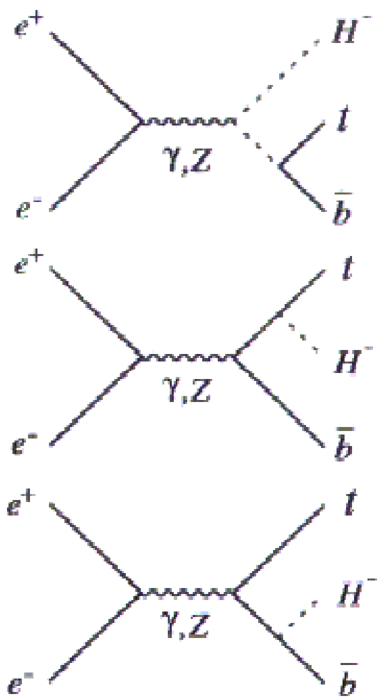
In the limit $m_A \gg M_Z$, the lightest $h \to h_{SM}$. Its couplings insensitive to $\tan\beta$.

B. Heavy Higgs boson production $(H^+H^-, AH, ZH...)$ at e^+e^- colliders[||]

To determine $\tan\beta$, Feng and Moroi[**] considered:

$$e^+e^- \to \bar{t}bH^+,\ t\bar{b}H^-$$

where both $\tan\beta$ and $\cot\beta$ involved.

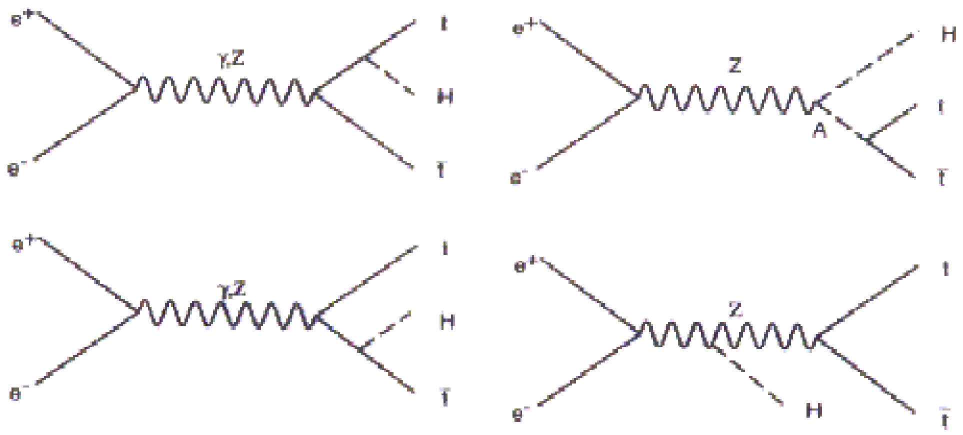


[||]Djouadi, Kalinowski, Ohmann, Zerwas; Gunion, Kelly

[**]Phys. Rev. **D56**, 5962 (1997)

In this study,[††] we consider the complementary processes:

$$e^+e^- \to Ht\bar{t},\ Hb\bar{b};\quad At\bar{t},\ Ab\bar{b}.$$



Advantage:

$Ht\bar{t} \sim m_t \cot\beta$,

and $Hb\bar{b} \sim m_b \tan\beta$.

$\Rightarrow$ separation of $\tan\beta$ vs. $\cot\beta$

interplay of $b\bar{b}$ vs. $t\bar{t}$

Somewhat smaller $4b$ and $4t$ backgrounds.

[††]Barger, Han, Jiang: hep-ph/0006223.

C. Input SUSY parameters:

• In MSSM:

Higgs sector parameters at Tree level:

$\tan\beta$ and m_A.

Other SUSY parameters:

$$m_Q, \quad m_U, \quad m_D, \quad \mu,$$
$$M_1, \quad M_2, \quad A_U, \quad A_D.$$

• In mSUGRA:

$$m_0, \quad m_{1/2}, \quad A_0$$

plus $\tan\beta$ and sign(μ).

For illustration, we choose:

- In mSUGRA, fix:

$m_0 = 250$ GeV, $m_{1/2} = 150$ GeV, $A_0 = -300$ GeV.

Varying $\tan\beta$ leads to:[‡‡]

$\tan\beta$	m_A	m_H	$m_{\chi^\pm}$	m_{χ^0}	μ	m_Q
3	434	438	105	56	315	360
10	373	373	110	57	274	359
30	273	273	112	59	264	337

- In MSSM:

$$\mu = 272 \text{ GeV}, \; m_Q = 356 \text{ GeV}, \; m_U = 273 \text{ GeV},$$
$$m_{\chi^\pm} = 111 \text{ GeV}, \quad m_{\chi^0} = 59 \text{ GeV}.$$

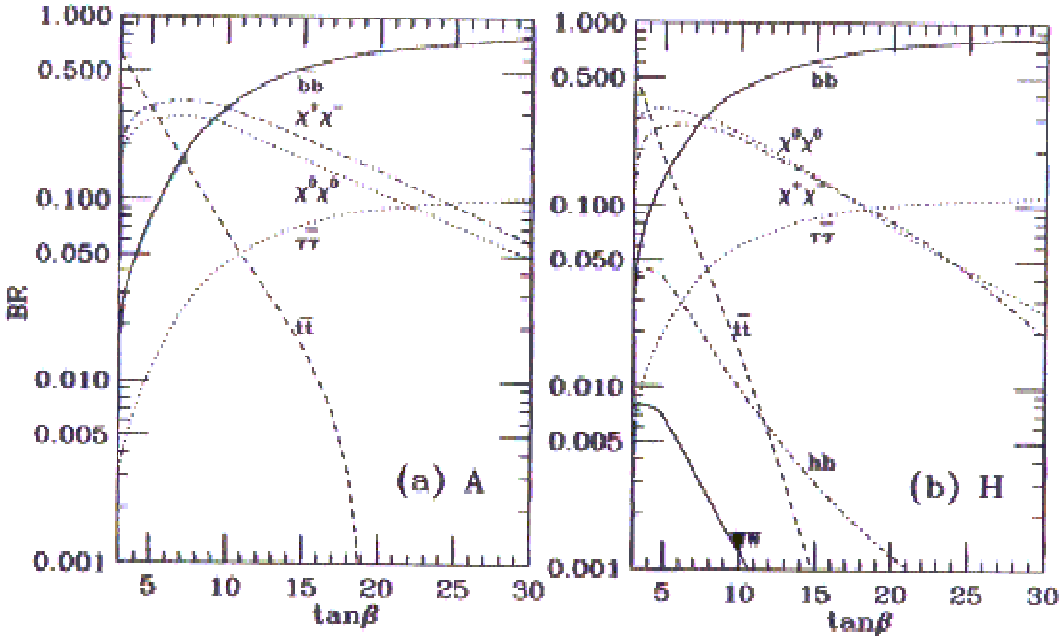
which is similar to mSUGRA with $\tan\beta = 15$.

Vary $\tan\beta$ and take $m_A = 200,\ 400$ GeV.

[‡‡]ISAJET: Paige, Protopescu, Baer, Tata

D. Heavy Higgs boson decay H, A:*

- In mSUGRA, BR vs. $\tan\beta$:

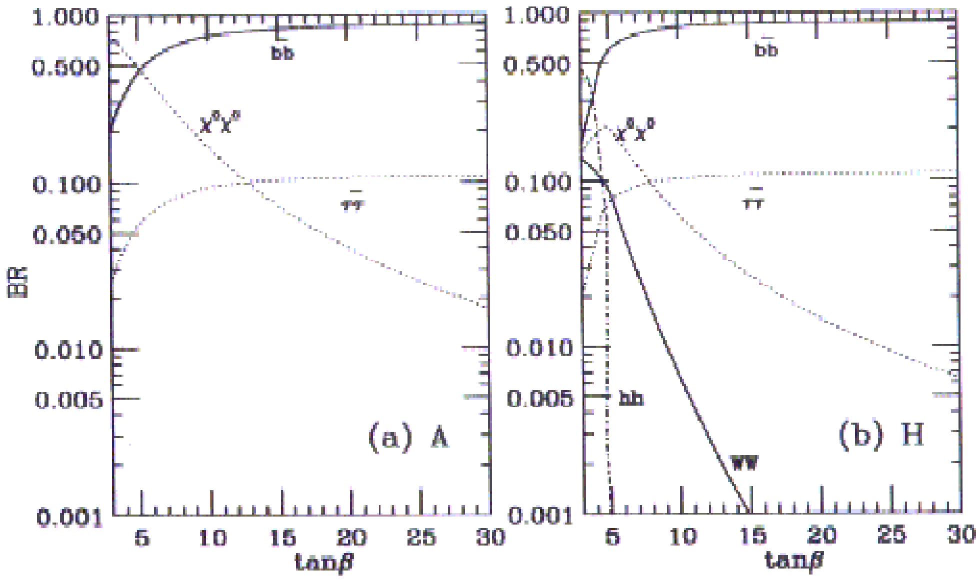


- strong dependence on $\tan\beta$;
- $t\bar{t}$ dominant at low $\tan\beta \lesssim 3$;
- $b\bar{b}$ dominant at high $\tan\beta \gtrsim 15$;
- $\chi^+\chi^-$ important near $\tan\beta \approx 7$.

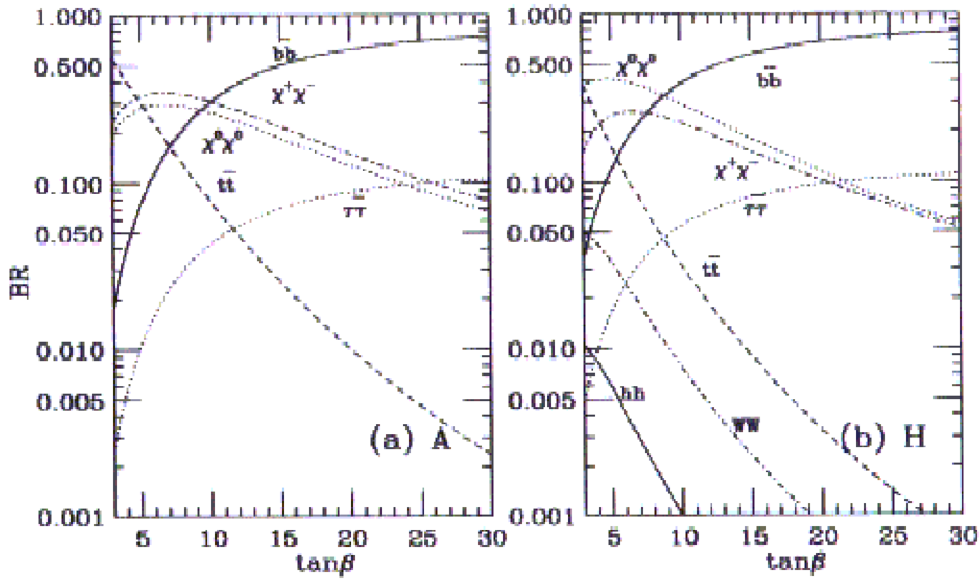
*HDECAY: Djouadi, Kalinowski, Spira

- In MSSM, BR vs. $\tan\beta$:

$m_A = 200$ GeV :



$m_A = 400$ GeV :

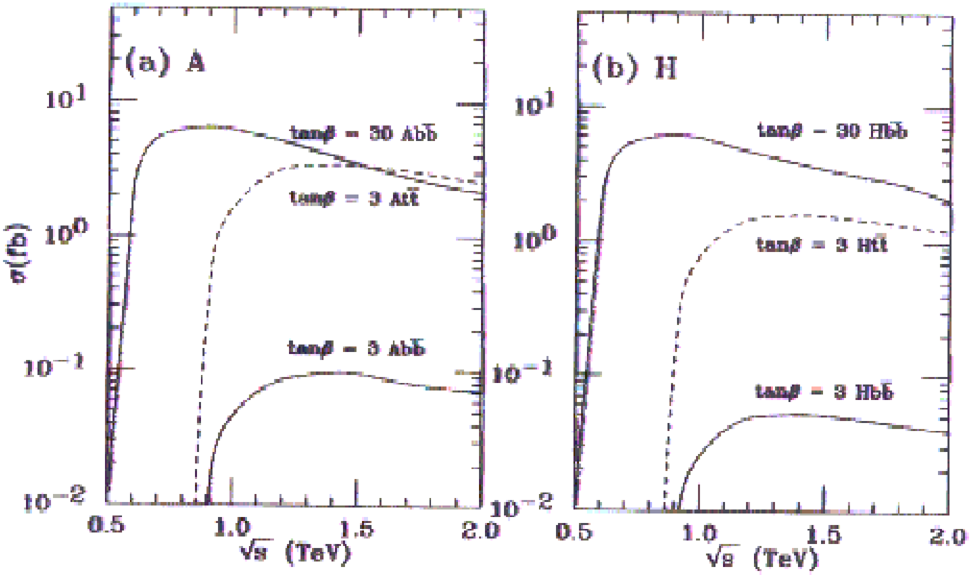


E. Production rate

$e^+e^- \to Ht\bar{t},\ Hb\bar{b};\ At\bar{t},\ Ab\bar{b}$

- cross section vs. c.m. energy $\sqrt{s}$,

in mSUGRA:



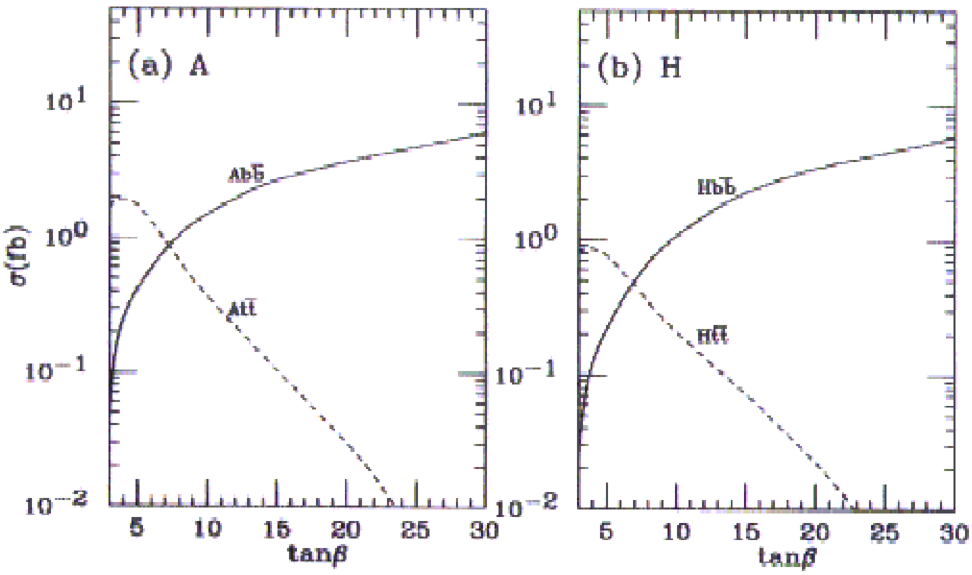
Cross sections peak near

$\sqrt{s} \approx m_A + m_H + 300$ GeV;

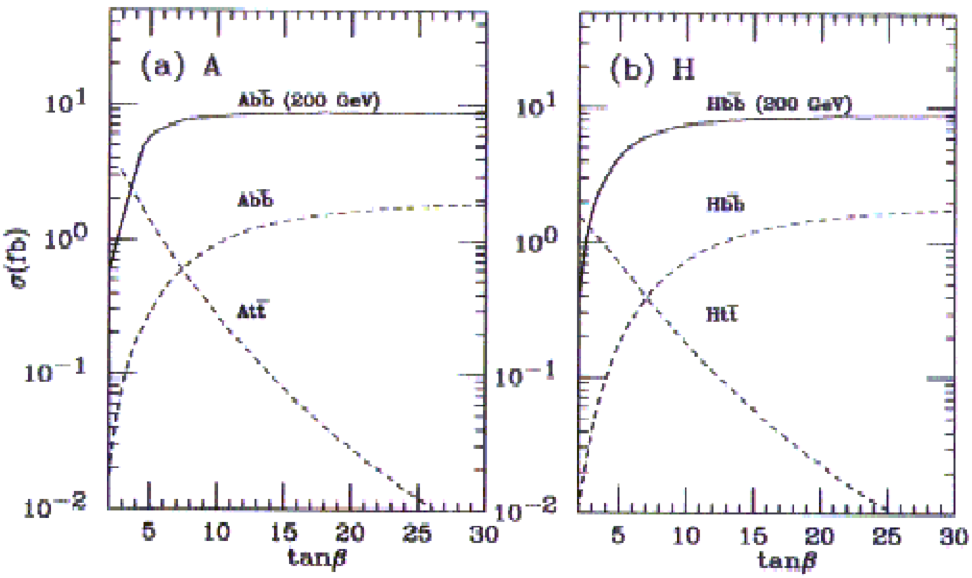
Two-body channel $e^+e^- \to HA$ dominates.

- cross section vs. $\tan\beta$:

in mSUGRA :

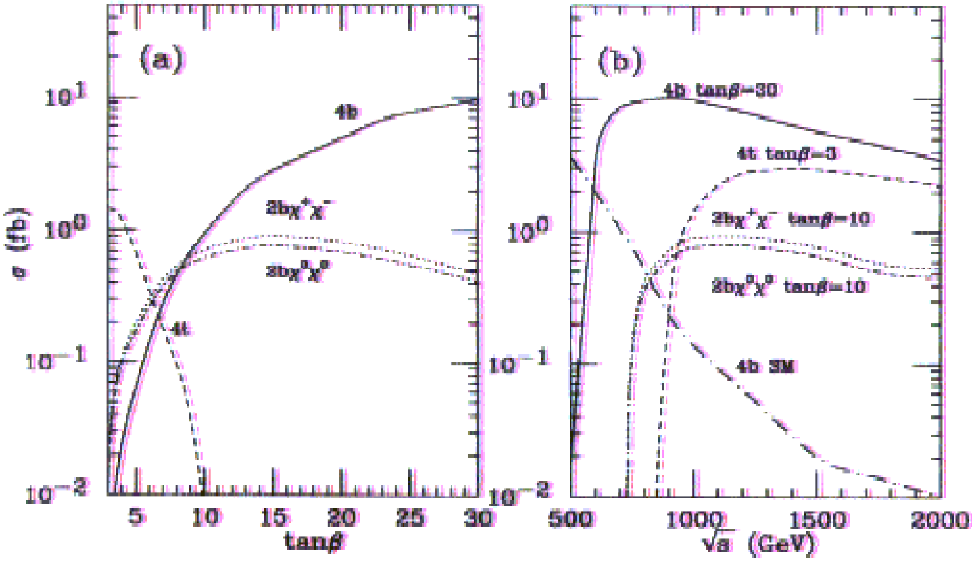


in MSSM :

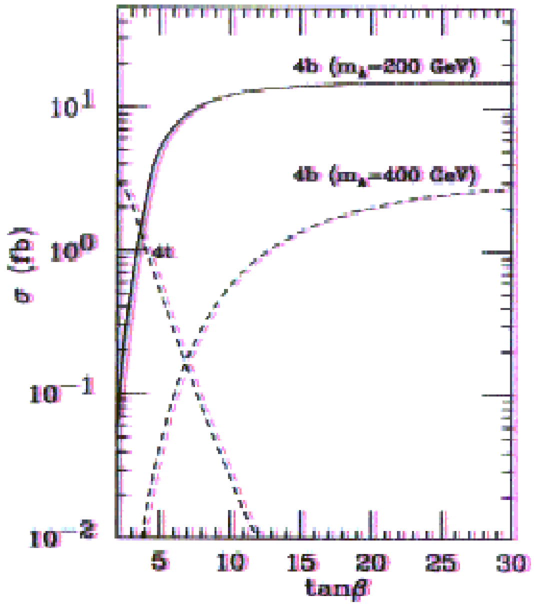


- cross section with decay vs. $\tan\beta$:

in mSUGRA :



in MSSM :



III. Sensitivity on probing $\tan\beta$

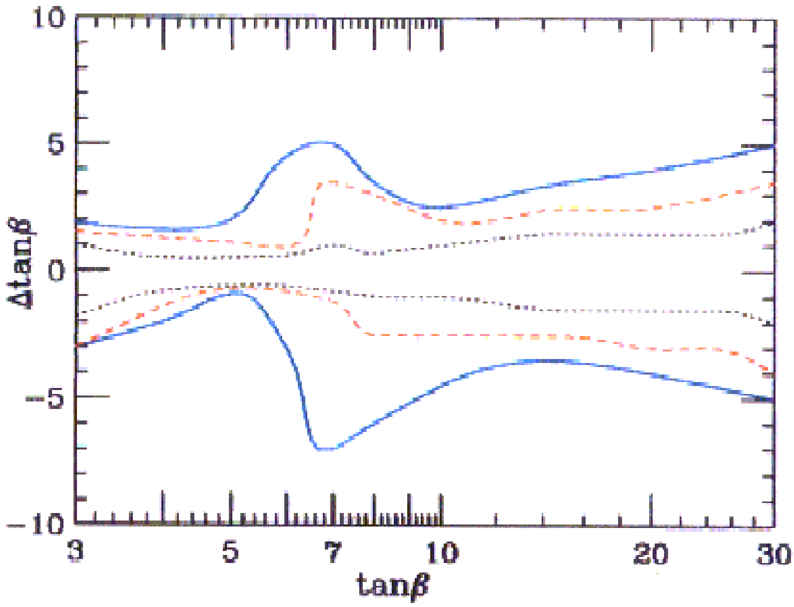
$$\Delta\tan\beta = \tan\beta_{\pm} - \tan\beta,$$

where $\tan\beta$ from N_S; $\tan\beta_{\pm}$ from

$$N_S \pm 1.96\sqrt{N_S + N_B}.$$

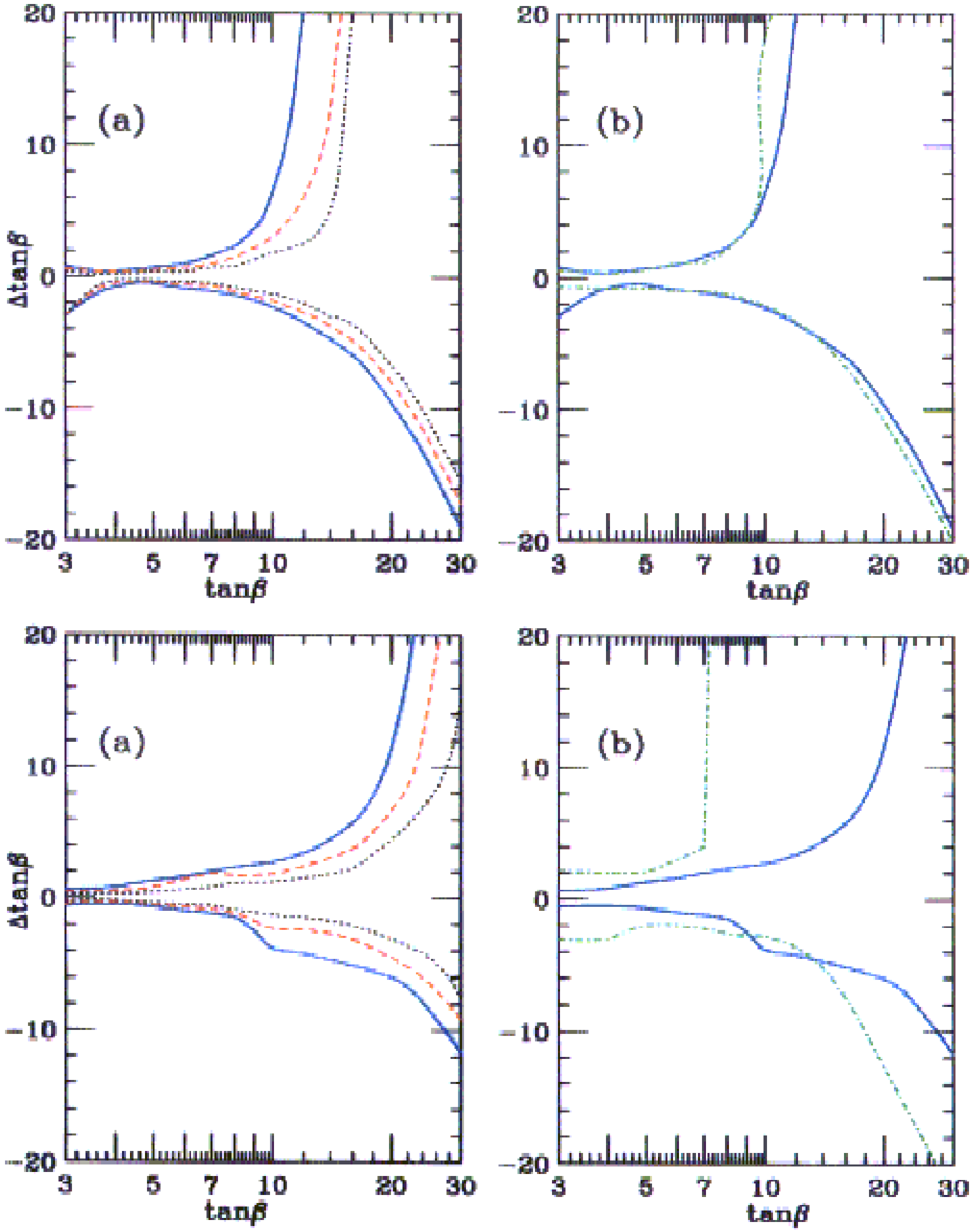
Event selection: $\cos(\theta_b) < 0.9$, $\epsilon_b = 65\%$
and $3b$-tagging: $4\epsilon_b{}^3 - 3\epsilon_b{}^4 \approx 56\%$.

- In mSUGRA:



$\Rightarrow$ $\tan\beta \approx 3 \pm 3$ or 30 ± 5 for 50 fb^{-1}
$\tan\beta \approx 3 \pm 2$ or 30 ± 2 for 500 fb^{-1}
Harder near $\tan\beta \approx 6$.

- In MSSM:



⇒ typically, $\tan\beta \approx 3 \pm 2$ or 10 ± 4

IV. Conclusions:

For $e^+e^- \to Ht\bar{t},\ Hb\bar{b};\quad At\bar{t},\ Ab\bar{b}$
at $\sqrt{s_{ee}} = 0.5{-}1$ TeV, with $50 - 500$ fb^{-1}:

- $4t$ and $4b$ final states interplay
  for low and high $\tan\beta$;

- $H(A)t\bar{t},\ H(A)b\bar{b}$ somewhat better than $H^{\pm}t\bar{b}$;

- In mSUGRA, good sensitivity;
  $\tan\beta \gtrsim 10 \Rightarrow 15\%$ or better

- In MSSM, good sensitivity for $\tan\beta \lesssim 10$;
  sensitivity weakened for higher values.

Discrimination of $\tan\beta \sim 2$ and > 30
$\Rightarrow$ testing GUTs scenarios.