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Sensitivity on $\tan \beta$
at a Future e^+e^- LC

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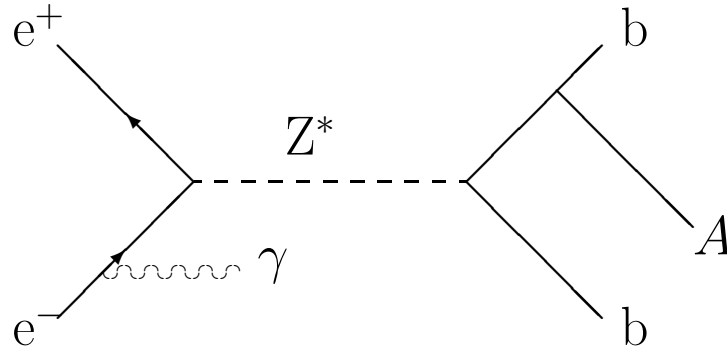
Outline

- Introduction
- $e^+e^- \rightarrow b\bar{b}A \rightarrow b\bar{b}b\bar{b}$ production rate
- $e^+e^- \rightarrow HA \rightarrow b\bar{b}b\bar{b}$ production rate
- H and A decay width from $HA \rightarrow b\bar{b}b\bar{b}$
- $e^+e^- \rightarrow H^+H^- \rightarrow t\bar{t}b\bar{b}$ production rate
- H^\pm decay width from $H^+H^- \rightarrow t\bar{t}b\bar{b}$
- Complementarity of methods
- $\tan \beta$ sensitivity LC/LHC
- Conclusions

Introduction

- Framework:
Two-Higgs Doublet Model or MSSM.
- Production and Decay of A , h , H , and H^\pm .
- Considered reactions for TESLA:
strong dependence on $\tan \beta$.

$b\bar{b}A$ Simulation

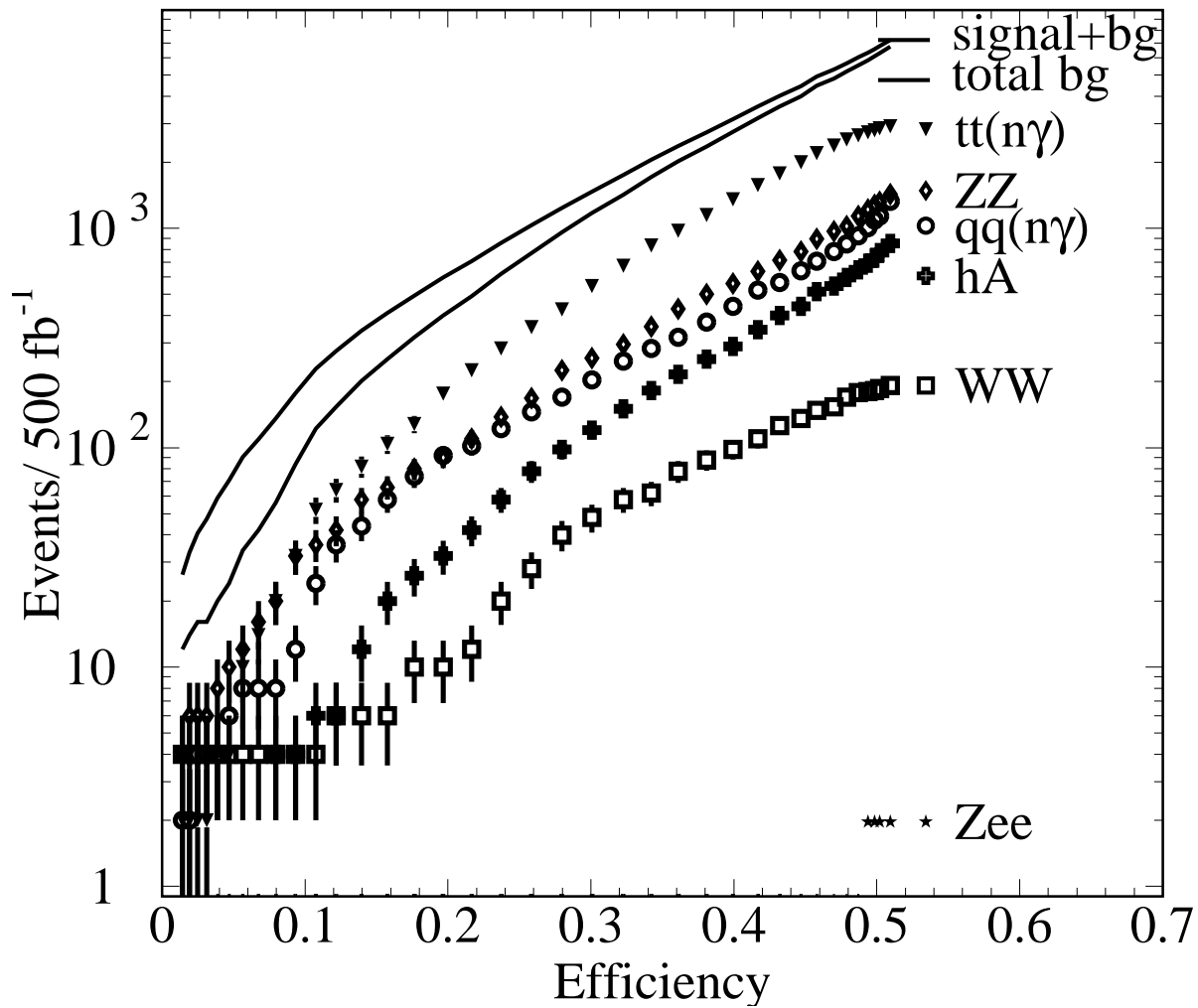


Simulated Higgs boson mass: 100 GeV

Channel	bbA	qq	WW	eW ν	tt	ZZ	eeZ	hA	sum
(in 1000)	50	6250	3500	2500	350	300	3000	50	16000
After Presel.	73%	20991	7481	0	89983	10278	145	12665	141544

Simulated hA rate corresponds to twice the luminosity (maximum cross section in general Two-Higgs Doublet Model).

Signal and Background



2HDM: $b\bar{b}A$ 500 fb^{-1} Results

For $\tan \beta = 50$ and $m_A = 100 \text{ GeV}$:

$$\Delta \tan \beta / \tan \beta = 0.07.$$

$$\Delta \tan^2 \beta / \tan^2 \beta = \Delta N_{\text{signal}} / N_{\text{signal}}$$

$$= \sqrt{N_{\text{signal}} + N_{\text{background}}} / N_{\text{signal}} = 0.14.$$

Smaller values of $\tan \beta$, the sensitivity decreases rapidly. 5σ signal detection for $\tan \beta = 35$.

MSSM: $b\bar{b}A$ 500 fb $^{-1}$ Results

$b\bar{b}h$ would double the number of signal events and have the same $\tan\beta$ dependence:

$$\Delta \tan^2 \beta / \tan^2 \beta \sim \sqrt{300}/200 \approx 0.085$$

For $\tan\beta = 50$ and $m_A = m_h = 100$ GeV:

$$\Delta \tan \beta / \tan \beta = 0.04.$$

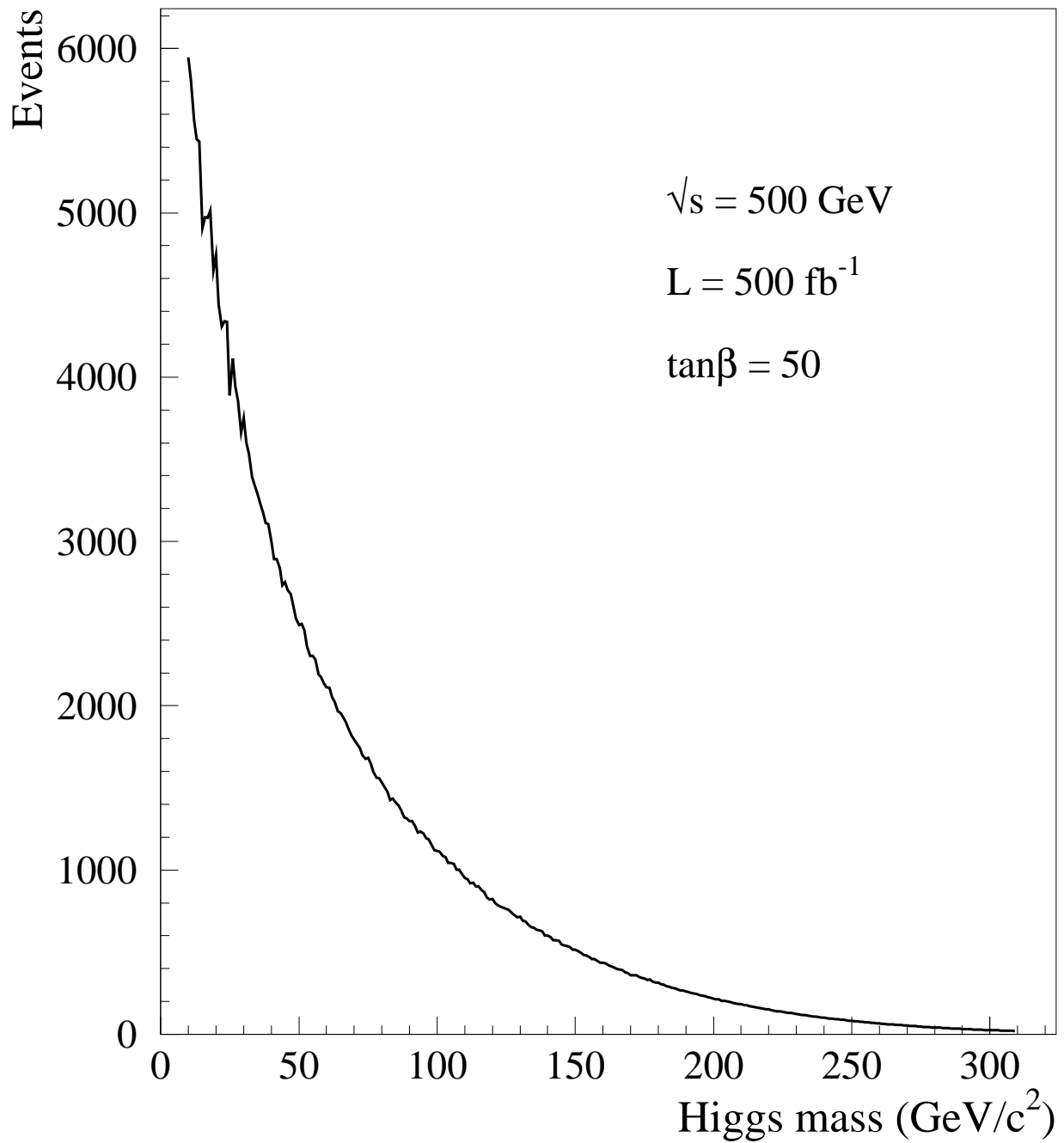
(For heavier A, $b\bar{b}H$ will contribute).

Experimental challenge:

at 10% efficiency, $\Delta \tan \beta / \tan \beta < 0.05$

requires $\Delta\epsilon/\epsilon < 0.1$, thus $\Delta\epsilon < 1\%$.

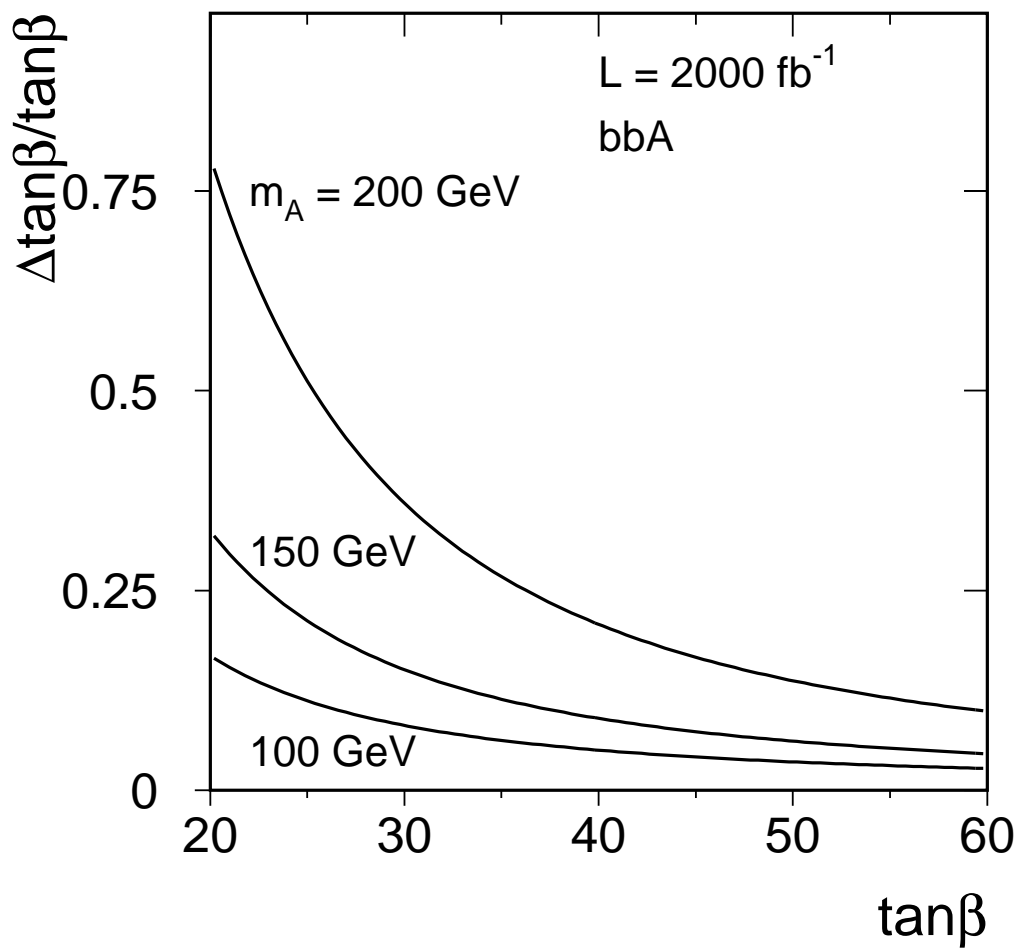
$e^+e^- \rightarrow b\bar{b} \rightarrow b\bar{b}A$ Rate



At 100 GeV: 1000 events.

At 200 GeV: 200 events.

$b\bar{b}A$ Results for 2000 fb^{-1}



$H A \rightarrow b\bar{b}b\bar{b}$ Event Rate

Assume b-tagging purity 80% per $b\bar{b}$ pair, thus 40% signal efficiency.

For $b\bar{b}b\bar{b}$: 16% efficiency.

Further reduction: kinematic event selection: final efficiency 10%, and negligible background.

Small $\tan \beta$: constant MSSM cross section and large variation of branching fraction.

Typical expected signal rate for 2000 fb^{-1} and $m_A = m_H = 200 \text{ GeV}$ for $\tan \beta = 5$: 500 events.

$$\Delta \tan \beta / \tan \beta \approx 0.01$$

Good overlap with $b\bar{b}A$ results.

MSSM Interpretation

Model (I) Heavy SUSY particles

$$m_{\tilde{g}} = 1 \text{ TeV}, \mu = M_2 = 250 \text{ GeV},$$

$$m_{\tilde{t}_L} = m_{\tilde{b}_L} = m_{\tilde{t}_R} = m_{\tilde{b}_R} \equiv m_{\tilde{t}} = 1 \text{ TeV},$$

$$A_b = A_\tau = 0, A_t = \mu/\tan\beta + \sqrt{6}m_{\tilde{t}}$$

(maximal mixing);

Model (II) Higgs into SUSY decays possible

$$m_{\tilde{g}} = 350 \text{ GeV}, \mu = 272 \text{ GeV}, M_2 = 120 \text{ GeV},$$

$$m_{\tilde{t}_L} = m_{\tilde{b}_L} = 356 \text{ GeV}, m_{\tilde{t}_R} = 273 \text{ GeV},$$

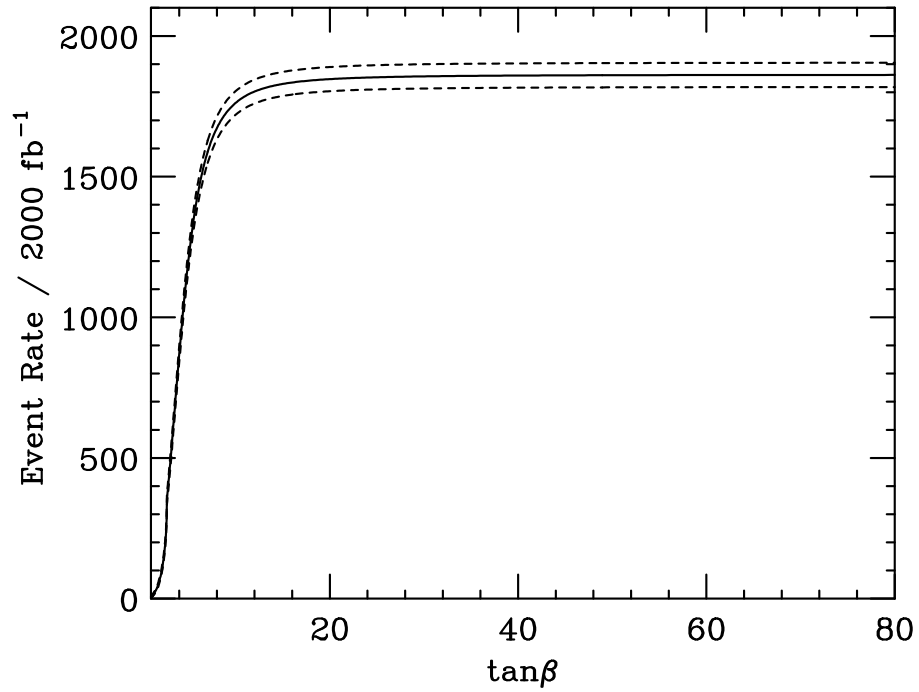
$$m_{\tilde{b}_R} = 400 \text{ GeV}, A_\tau = 0, A_b = -672 \text{ GeV},$$

$$A_t = -369 \text{ GeV}.$$

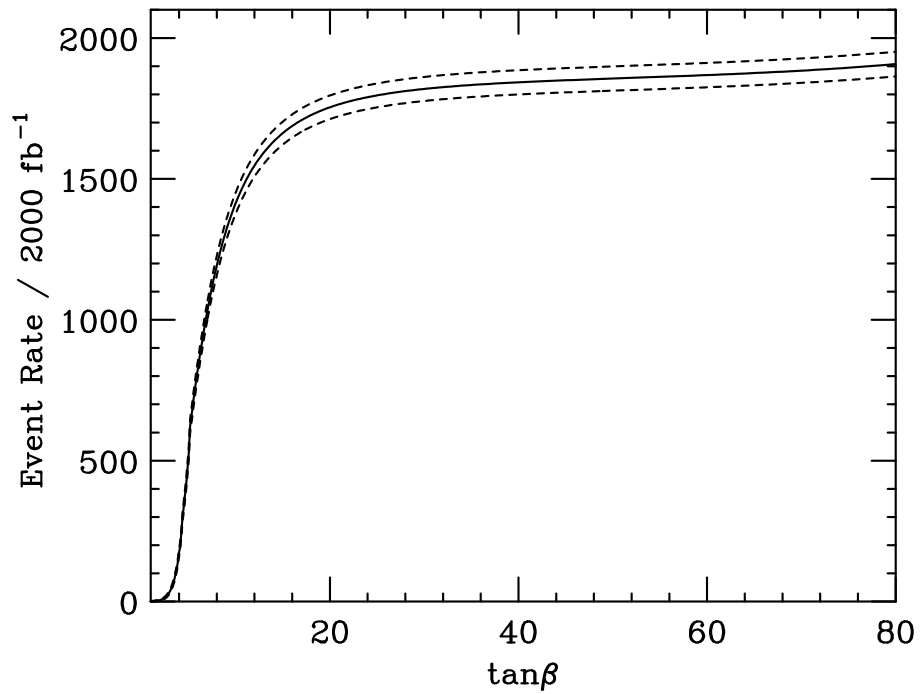
bbA and H,A decay widths results almost independent of model (I) or (II).

$H A \rightarrow b\bar{b}b\bar{b}$ Event Rate

$b\bar{b}b\bar{b}$ rate and 1σ upper and lower bounds: scenario (I)



$b\bar{b}b\bar{b}$ rate and 1σ upper and lower bounds: scenario (II)



H and A width from $HA \rightarrow b\bar{b}b\bar{b}$

Assumption: 5 ± 0.5 GeV detector resolution
($\Delta E/E = 0.3/\sqrt{E}$ and conservative error).

Reconstruction of mean H and A widths from
 $b\bar{b}$ -mass.

There are two $b\bar{b}$ masses per event.

Wrong jet-jet pairings: 25%.

Available statistics for mass reconstruction:

1.5 $HA \rightarrow b\bar{b}b\bar{b}$ rate.

Determination of intrinsic Higgs width
by convolution with detector resolution.

$$0.5(\Gamma_H + \Gamma_A) = 12.5 \pm 0.54 \text{ GeV},$$

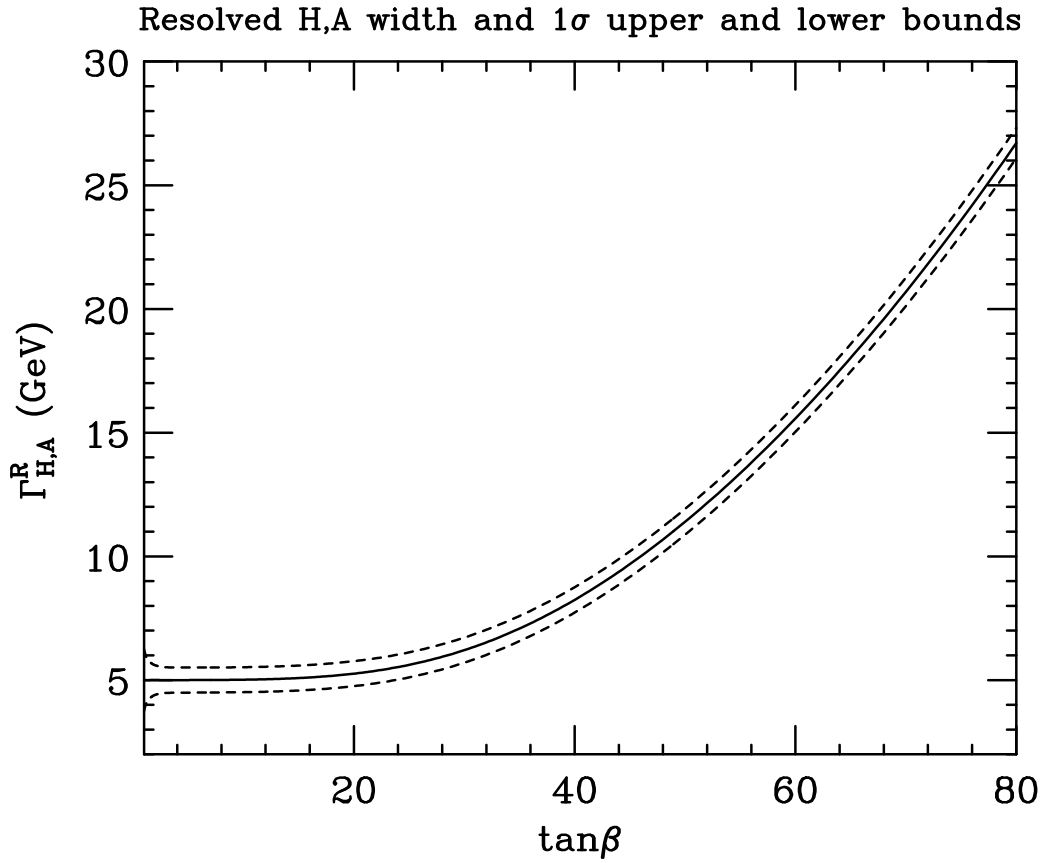
dominated by error on detector resolution.

$$\Delta \tan \beta / \tan \beta < 0.02 \text{ for } \tan \beta = 55.$$

Resolved Average H/A Width

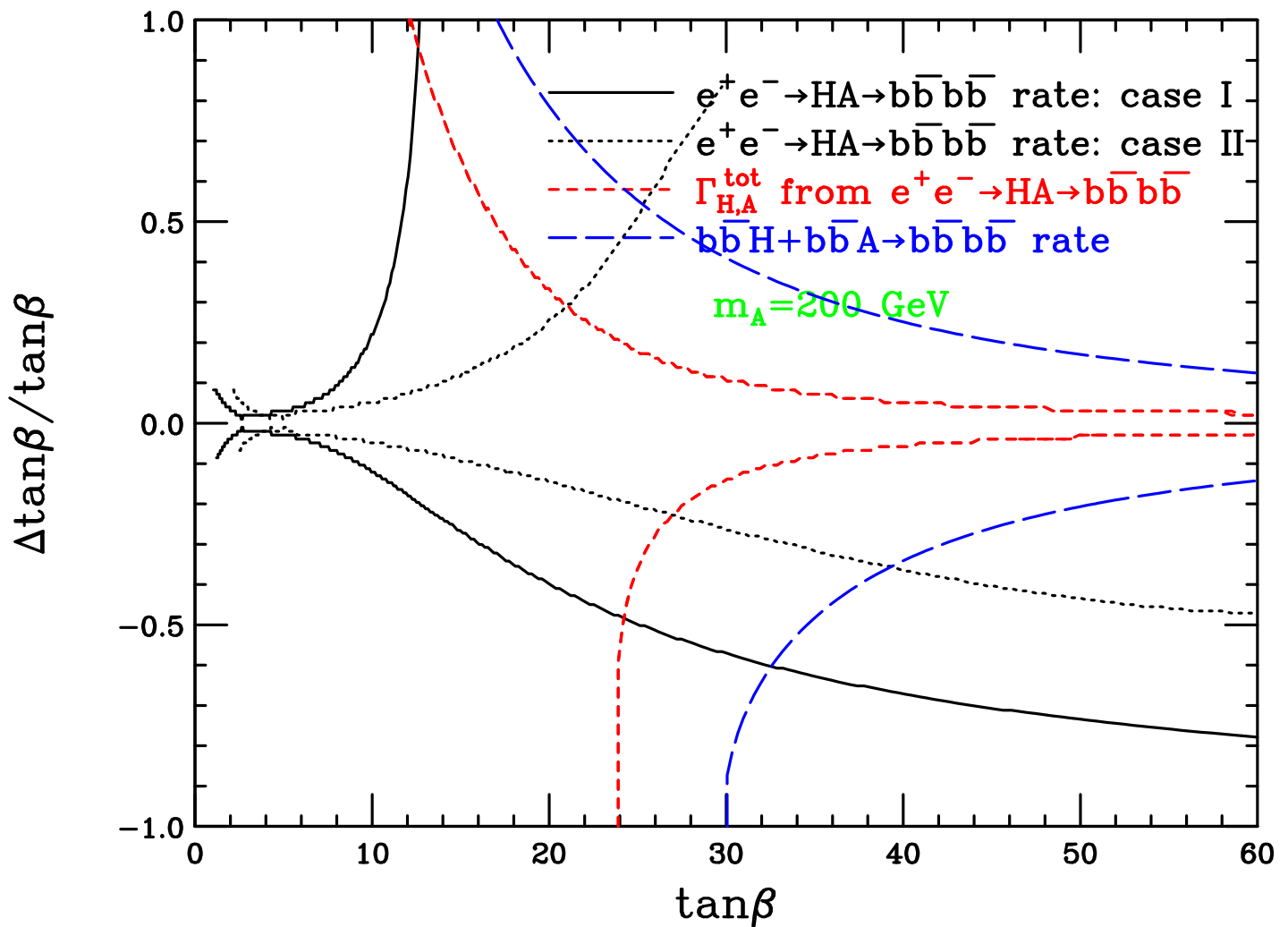
$$\Gamma_{H,A}^R = \frac{1}{2} \left[\sqrt{[\Gamma_{\text{tot}}^H]^2 + [\Gamma_{\text{res}}]^2} + \sqrt{[\Gamma_{\text{tot}}^A]^2 + [\Gamma_{\text{res}}]^2} \right]$$

$$\Delta\Gamma_{H,A}^R = \left[\left(\frac{\Gamma_{H,A}^R}{\sqrt{2N_{\text{entries}}}} \right)^2 + (\Delta\Gamma_{\text{res}}^{\text{sys}})^2 \right]^{1/2}$$



Complementarity of Different Neutral Higgs Boson Methods

Determination of $\tan\beta$: $\sqrt{s}=500$ GeV, $L=2000$ fb $^{-1}$



(I) Heavy SUSY particles.

(II) Possible $H, A \rightarrow \chi_1^0 \tilde{\chi}_1^0$ decays.

$$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}t\bar{b}$$

- 500 GeV and 10 fb^{-1} ,

the charged Higgs can be reconstructed

Z. Phys. C **65** (1995) 449.

- 800 GeV and 1000 fb^{-1} ,

high precision reconstruction,

M. Battaglia, A. Ferrari, A. Kiiskinen, T.M. Ki,

hep-ph/0112015.

- Sensitivity for 500 GeV and 1000 fb^{-1} ,

for a 200 GeV charged Higgs boson mass:

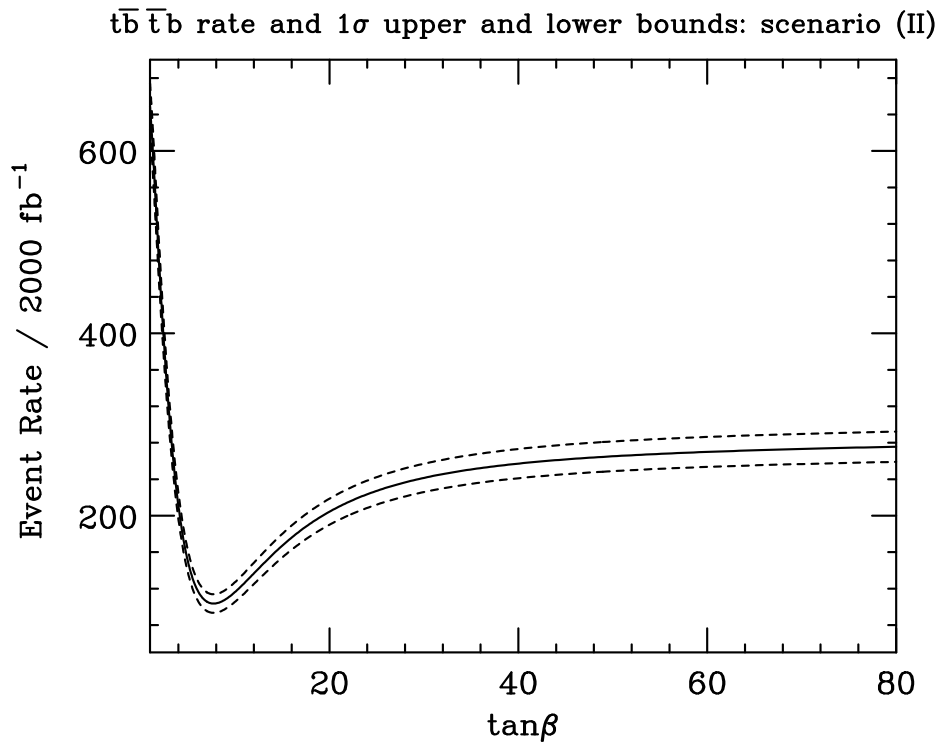
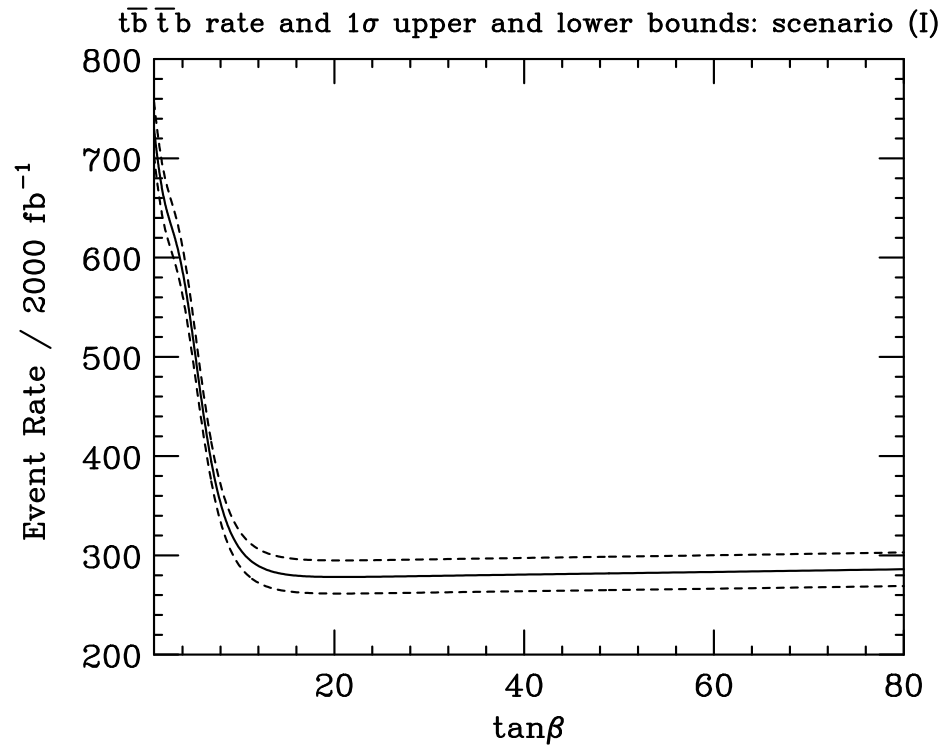
small intrinsic width and reconstruction uncertainty dominated by detector resolution.

- 2.2% selection efficiency.

$H^\pm \rightarrow t\bar{b}$ branching ratio is sensitive to $\tan \beta$:

$$\Gamma(H^\pm \rightarrow t\bar{b}) \propto m_\tau^2 \cot^2 \beta + m_b^2 \tan^2 \beta$$

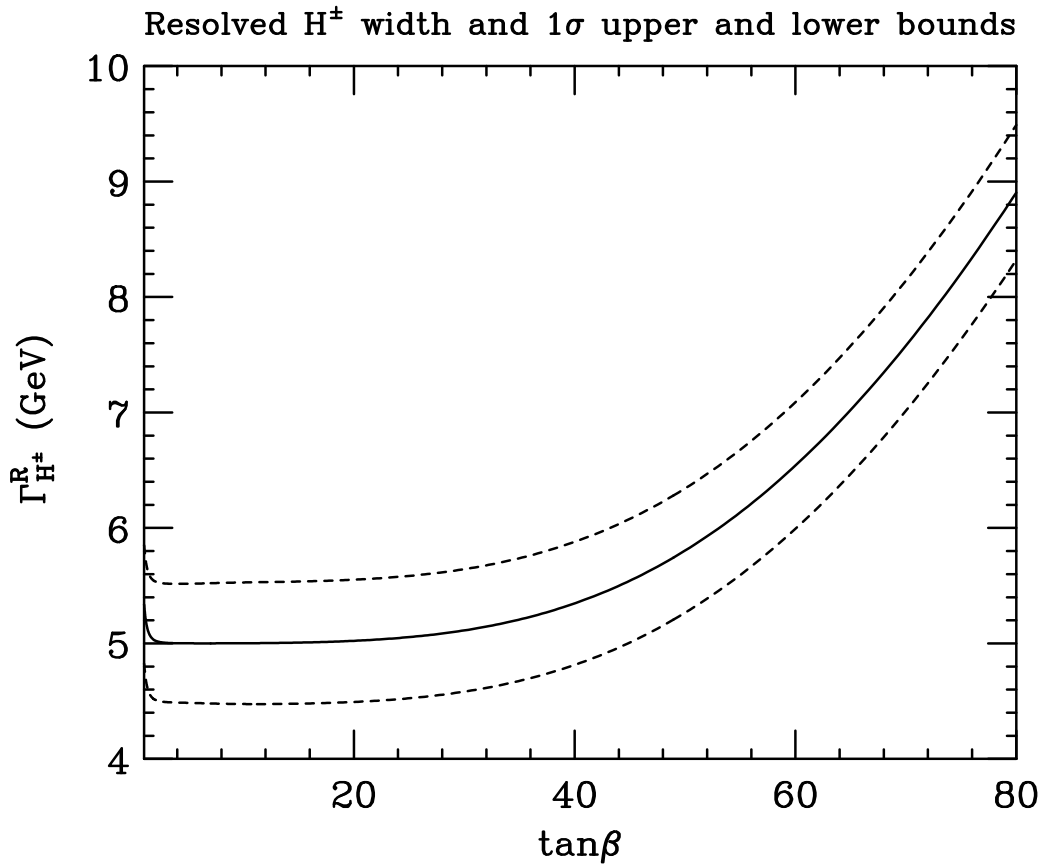
$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{t}b\bar{b}$ Rate



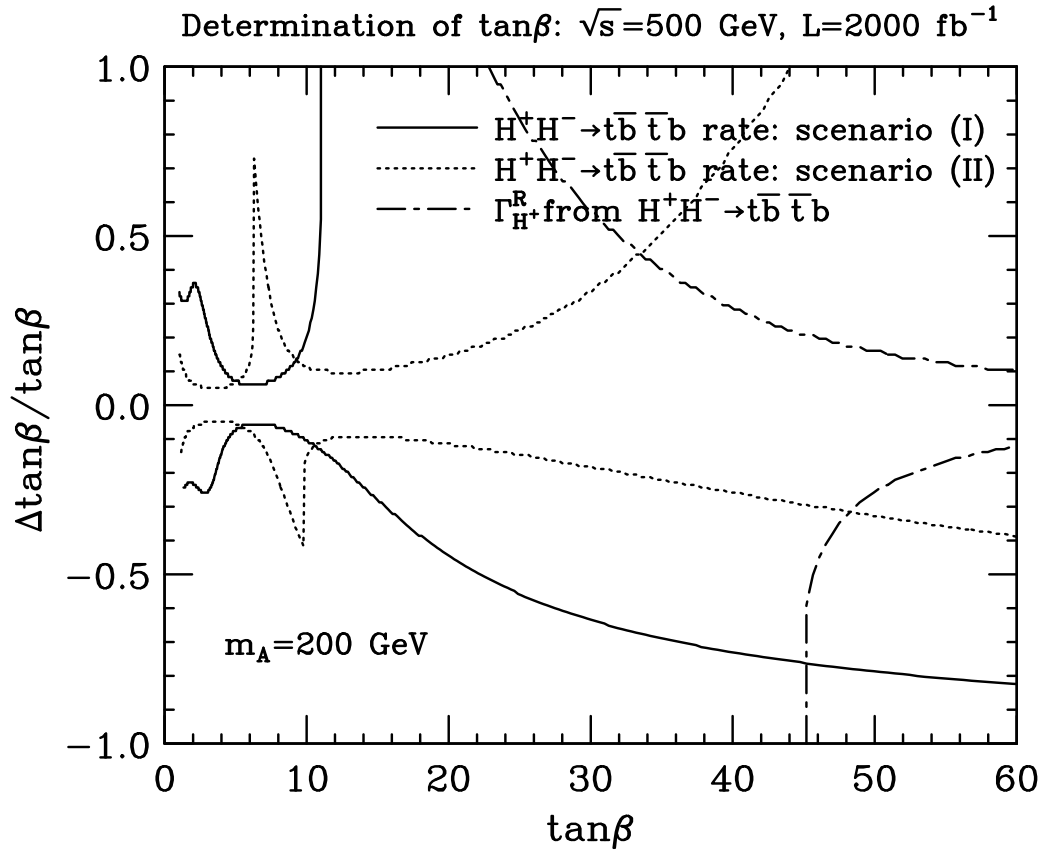
Resolved H^\pm Width

$$\Gamma_{H^\pm}^R = \sqrt{[\Gamma_{\text{tot}}^{H^\pm}]^2 + [\Gamma_{\text{res}}]^2}.$$

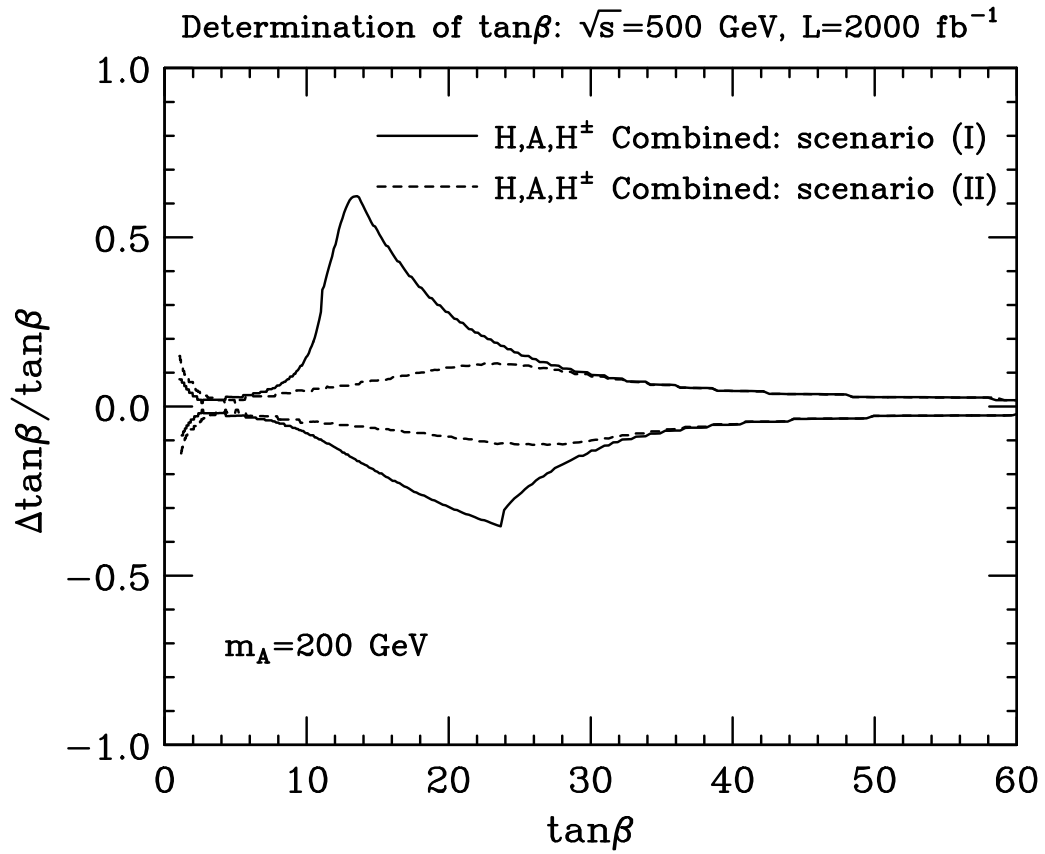
Intrinsic resolution $\Gamma_{\text{res}} = 5 \text{ GeV}$.



Combined H^\pm Results



H/A and H[±] Combined Results



Relation to LHC $\tan \beta$ Determination

MSSM: $(m_h, m_A) = 200$ GeV. $\Delta \tan \beta / \tan \beta$,

$\mathcal{L} = 2000 \text{ fb}^{-1}$ LC, cf. $\mathcal{L} = 300 \text{ fb}^{-1}$ LHC

tan β range	LHC	LC (case I)	LC (case II)
1	0.12	0.15	0.1
1.5–5	very large	0.03–0.05	0.03–0.05
10	0.12	0.1	0.05
13–30	0.05	0.6–0.1	0.05–0.1
40–60	0.05–0.03	0.05–0.025	0.05–0.025

LHC maximal mixing results from combining the determinations H, A production from ATLAS, TDR, CERN/LHCC/99–14/15 and H^\pm production from K.A. Assamagan, etal, EPJdirect C **4**, 9 (2002).

Conclusions

- LC neutral and charged Higgs boson channels lead to good $\tan \beta$ sensitivity over a large parameter range.
- Complementary $e^+e^- \rightarrow bbA$ (large $\tan \beta$) and $HA \rightarrow b\bar{b}b\bar{b}$ (small $\tan \beta$).
- Additional sensitivity from $H^+H^- \rightarrow t\bar{t}b$.
- Korea LCWS proceedings: hep-ph/0211123.
- Preprint: hep-ph/0212151.
- $\tan \beta$ sensitivities could contribute to MSSM fits.
- LC-LHC : Regardless of relative LHC vs LC errors, clean LC environment will provide an important and independent measurement.
- Different uncertainties associated with $\tan \beta$ determination at hadron and e^+e^- collider because of the different backgrounds.
- LHC and LC measurements of $\tan \beta$ will be highly complementary in that systematic errors involved will be very different.