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Determination of $\tan\beta$ at a Future e^+e^- LC

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Outline

- Introduction
- $b\bar{b}A \rightarrow b\bar{b}b\bar{b}$ simulation
- High luminosity: 2000 fb^{-1}
- $HA \rightarrow b\bar{b}b\bar{b}$ event rate
- H and A width from $HA \rightarrow b\bar{b}b\bar{b}$
- New aspect: $H^+H^- \rightarrow t\bar{b}\bar{t}b$
- Conclusions

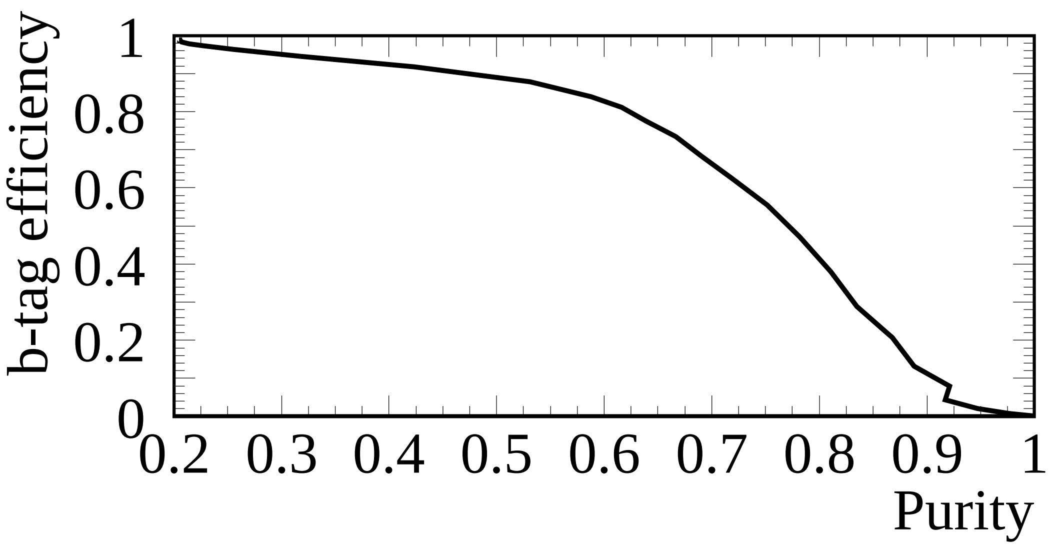
Introduction

- Framework:
  Two-Higgs Doublet Model or MSSM.
- Production and Decay of A, h, H, and $H^{\pm}$.
- Considered reactions for TESLA:
  strong dependence on $\tan\beta$.
- Extrapolation $b\bar{b}A \rightarrow b\bar{b}b\bar{b}$ for $100 < m_A <$ 200 GeV.
- Estimate of $HA \rightarrow b\bar{b}b\bar{b}$ event rate.
- Estimate of H and A width determination.
- Estimate of charged Higgs bosons branching ratio and decay width.

b-tagging

Experimental potential depends strongly on the b-tagging performance.

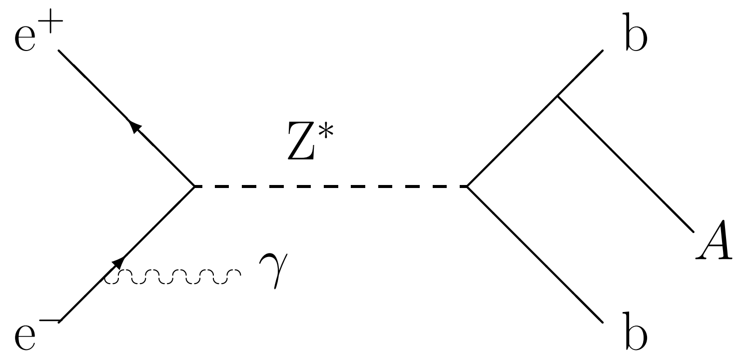
Hadronic events $e^+e^- \to q\bar{q}$ (5 flavors).



Efficiency: Ratio of simulated $b\overline{b}$ events after the selection to all simulated $b\overline{b}$ events.

Purity: Ratio of simulated $b\overline{b}$ events after the selection to all selected $q\overline{q}$ events.

$b\bar{b}A$ Simulation



Simulated Higgs boson mass: 100 GeV

Channel	bbA	qq	WW	eWν	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).

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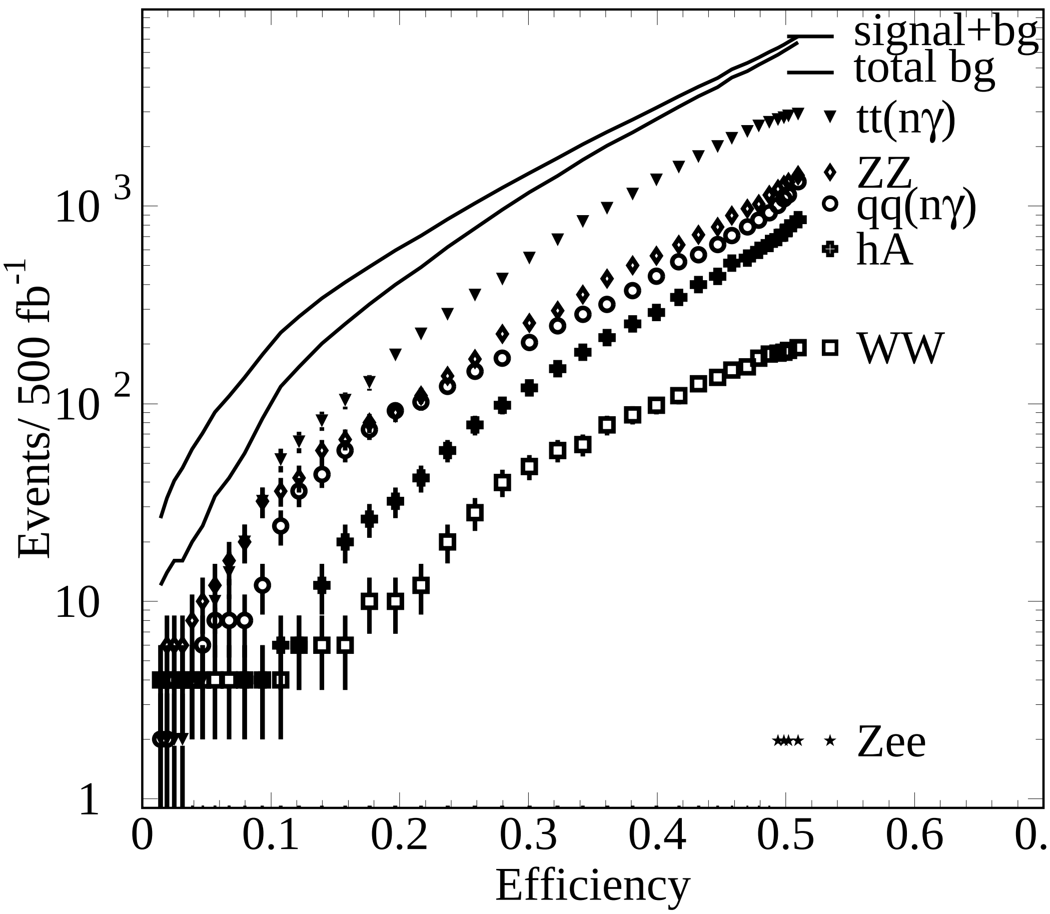
Signal and Background



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Interference: $\mathbf{b\overline{b}A}$ $\mathbf{hA \rightarrow b\bar{b}b\bar{b}}$

Expectation before event selection:

$\sigma_{\mathrm{bbA}} \equiv \sigma(\mathrm{e^+e^-} \rightarrow \mathrm{bbA} \rightarrow \mathrm{b\bar{b}b\bar{b}})$

$\sigma_{\mathrm{hA}} \equiv \sigma(\mathrm{e^+e^-} \rightarrow \mathrm{hA} \rightarrow \mathrm{b\bar{b}b\bar{b}})$

$\sigma_{\mathrm{b\overline{b}A+hA}} \equiv \sigma(\mathrm{e^+e^-} \rightarrow \mathrm{b\overline{b}A}, \mathrm{hA} \rightarrow \mathrm{b\bar{b}b\bar{b}})$

$\sigma_{\mathrm{interf}} = \sigma_{\mathrm{b\overline{b}A+hA}} - \sigma_{\mathrm{b\overline{b}A}} - \sigma_{\mathrm{hA}}.$

For $m_{\mathrm{b}} = 4.62$ GeV:

$\sigma_{\mathrm{b\overline{b}A}} = 1.83 \pm 0.01$ fb

$\sigma_{\mathrm{hA}} = 36.85 \pm 0.10$ fb

$\sigma_{\mathrm{b\overline{b}A+hA}} = 39.23 \pm 0.12$ fb

$\sigma_{\mathrm{interf}} = 0.55 \pm 0.16$ fb

Positive interference,

reduction in statistical error.

Interference: $\mathbf{b\bar{b}A}$ $\mathbf{hA \rightarrow b\bar{b}b\bar{b}}$

Expectation after event selection:

100 $b\bar{b}A \rightarrow b\bar{b}b\bar{b}$ events

2 ± 1 $hA \rightarrow b\bar{b}b\bar{b}$ events.

Maximum interference magnitude:

$$(10 + 1.4)^2 - 100 - 2 \approx 28$$

Similar ratio of interference to signal 30% before and after event selection.

Interference events:

background-like: small systematic error.

signal-like: large systematic error.

Solution: fit signal and background to data for various $\tan\beta$.

Another systematic error is the running b-mass. Higher-order corrections should be very precisely known by the time the LC is constructed.

$\mathrm{b\bar{b}A}$ Results for 500 fb^{-1}

For $\tan\beta = 50$ and $m_\mathrm{A} = 100$ GeV:

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

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

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

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

MSSM: $\mathrm{b\bar{b}h}$ 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 $m_\mathrm{A} = m_\mathrm{h} = 100$ GeV:

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

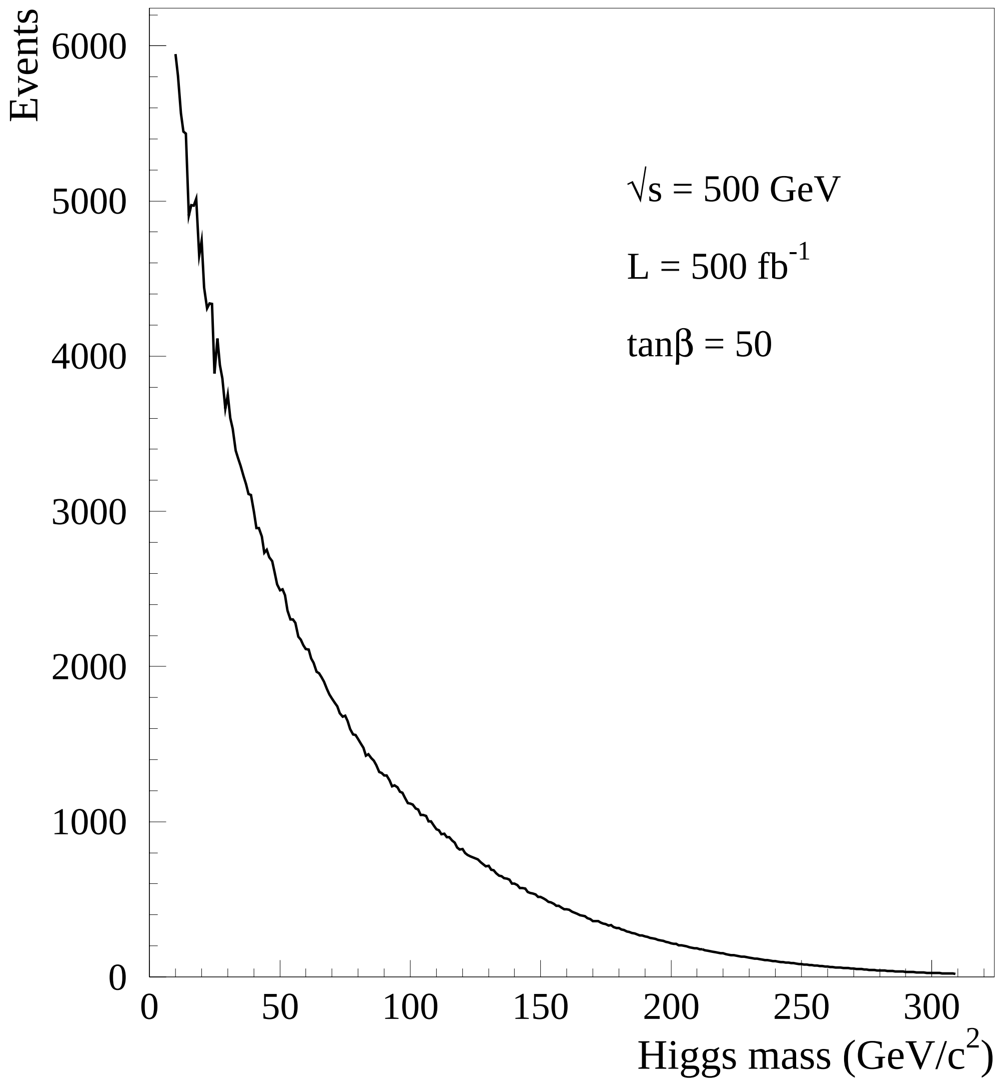
(For heavier A, $\mathrm{b\bar{b}H}$ will contribute).

Experimental challenge:

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

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

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



At 100 GeV: 1000 events.

At 200 GeV: 200 events.

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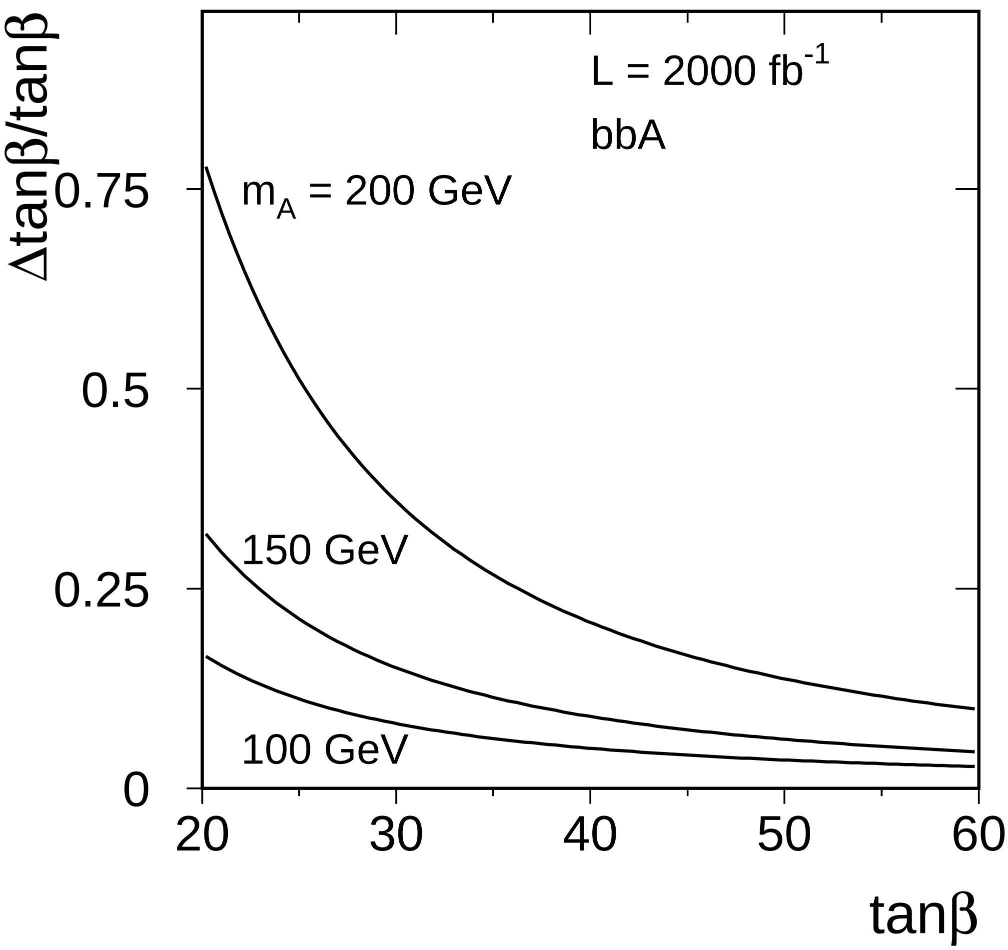
$b\bar{b}A$ Results for 2000 fb^{-1}



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$\mathbf{HA \rightarrow b\bar{b}b\bar{b}}$ 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 $m_\text{A} = m_\text{H} = 200$ GeV for $\tan\beta = 5$: 500 events.

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

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

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

Assumption: 5 ± 0.5 GeV detector resolution.

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 $HA \to b\bar{b}b\bar{b}$ rate.

Determination of intrinsic Higgs width by convolution with detector resolution.

$0.5(\Gamma_H + \Gamma_A) = 12.5 \pm 0.54$ GeV, dominated by error on detector resolution.

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

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

- 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:

  uncertainty about 0.5 GeV.

- Very similar uncertainty as for the HA.

- Similar precision on $\tan\beta$

  as from HA production

  $\Delta\tan\beta/\tan\beta \approx 0.02$ for $\tan\beta = 5$.

Further information on $\tan\beta$

- $\mathrm{tbH}^{\pm} \rightarrow \mathrm{tb}\tau\nu$

  J. L. Feng and T. Moroi, Phys. Rev. D **56**, 5962 (1997).

- A width from $\mathrm{b\overline{b}A} \rightarrow \mathrm{b\bar{b}b\bar{b}}$

- Scalar taus (E.Boos et.al.)

Conclusions

Experimental challenges:

- High luminosity needed.
- Best possible b-tagging performance.
- Precision detector resolution measurement.
- Combined analyses, e.g. Fit of all $b\bar{b}b\bar{b}$ processes as function of $\tan\beta$.
- Precision determination of signal efficiency.
- Precision cross section and decay width meas.
- $b\bar{b}A \rightarrow b\bar{b}b\bar{b}$
- $HA \rightarrow b\bar{b}b\bar{b}$
- $H^+H^- \rightarrow t\bar{b}\bar{t}b$

TESLA: Precision determination of $\tan\beta$ with different independent complementary methods.