Study of charged and neutral Higgs boson decays at CLIC

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Introduction

- In the Standard Model, only 1 doublet of Higgs scalars is responsible for the electroweak symmetry breaking. As a result, there is only one neutral Higgs boson h^0.
- Other theoretical models, in particular with Supersymmetry (MSSM), predict the existence of 2 complex Higgs doublets $\rightarrow$ 5 physical states: H^+, H^-, h^0, H^0 and A^0.
- At tree level, the MSSM Higgs sector is fully determined by two independent parameters only: m_A and $\tan\beta$.
- By comparing the signal rates of $H^\pm \rightarrow tb$ and $H^\pm \rightarrow \tau\nu$, or of $H^0/A^0 \rightarrow tt$ and $H^0/A^0 \rightarrow bb$, one can derive $\tan\beta$, whether or not the charged and neutral Higgs bosons also decay into non-SM particles.

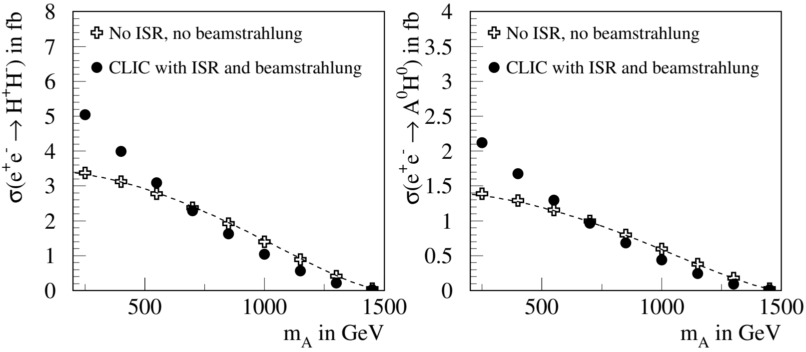
Monte-Carlo simulation studies

- The charged and neutral Higgs boson decay widths and branching ratios are computed with HDECAY.
- Signal events are generated with PYTHIA and the CLIC beam-beam effects (beamstrahlung, ISR, $\gamma\gamma \rightarrow$ hadrons) are included.
- The physics background events are generated with MadEvent/MadGraph. A home-made subroutine was written to include the CLIC beam-beam effects and PYTHIA is used for the fragmentation of the quarks.
- Fast detector simulation and event reconstruction with SIMDET, 70% tagging efficiency for b and τ jets.

CLIC beam parameters at 3 TeV

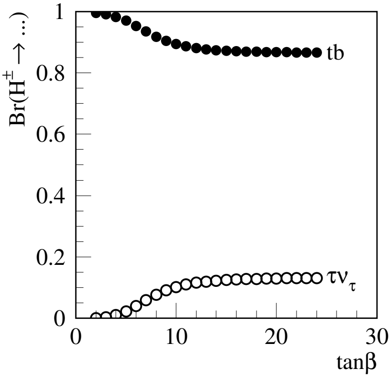
Center-of-mass energy	3	TeV
Main linac RF frequency	30	GHz
Accelerating gradient	150	MV/m
Linac and site lengths	28/33.2	km
Linac repetition rate	150	Hz
No. of bunches per pulse	220	
No. of particles per bunch	2.56	10^9
Bunch spacing	0.267	ns
Primary beam power	20.4	MW
Total site AC power	418	MW
Wall plug to main beam efficiency	12.5	%
Horizontal emittance $(\beta\gamma)\epsilon_x$	0.660	mm.mrad
Vertical emittance $(\beta\gamma)\epsilon_y$	0.001	mm.mrad
Horizontal beam size σ_x	60	nm
Vertical beam size σ_y	0.7	nm
Bunch length σ_z	30.8	μm
Peak luminosity	6.5	10^{34} cm^{-2} s^{-1}
Luminosity within 1% of E_{cm}	3.3	10^{34} cm^{-2} s^{-1}
Photons per e^+/e^-	1.1	
Beamstrahlung loss	16.0	%
Coherent pairs per bunch crossing	5	10^7
$\gamma\gamma \rightarrow$ hadrons per bunch crossing	0.73	

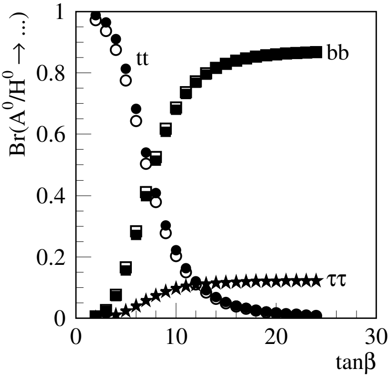
Charged and neutral Higgs boson pair production



In the following, we use an integrated luminosity of 3000 fb^{-1}.

Charged and neutral Higgs boson decays

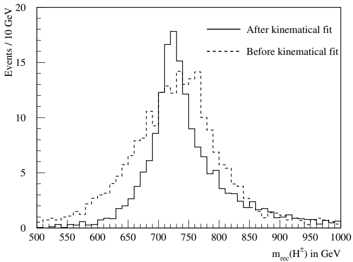




In the following, we assume that the charged and neutral Higgs bosons only decay into SM particles.

$e^+e^- \to H^+H^- \to tbtb$

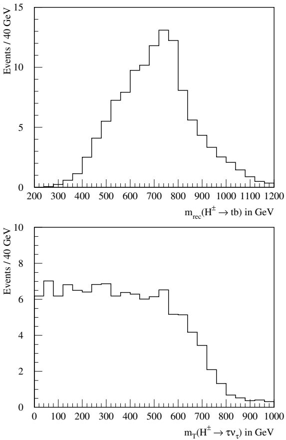
- Events with no isolated lepton, at least 8 jets including 4 b-jets,
- Assignment of the non-b jets to 2 W bosons, reconstruction of top quarks and of the charged Higgs bosons,
- Mass constrained kinematical fit to improve the reconstruction.



A cut on m_{bb} is then applied to further reduce the $e^+e^- \to tbtb$ background.

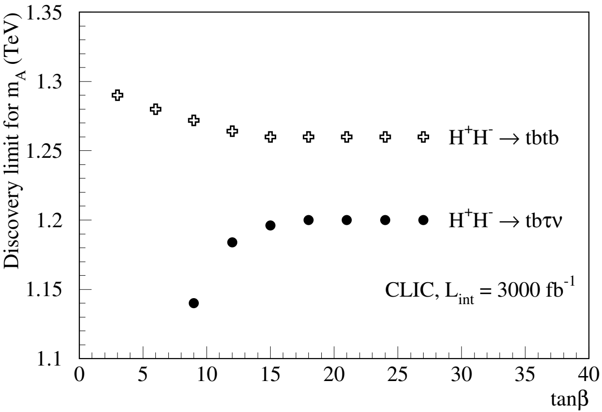
$e^+e^- \rightarrow H^+H^- \rightarrow tb\tau\nu$

- Events with no isolated lepton, at least 5 jets including 2 b-jets and 1 τ-jet,
- Assignment of 2 non-b jets to a W boson, reconstruction of the top quark and of $H^\pm \rightarrow tb$,
- Transverse mass reconstruction for $H^\pm \rightarrow \tau\nu$.



Cuts on the missing P_T, on the transverse angle between the charged Higgs boson candidates and on the transverse mass are applied to further reduce the $e^+e^- \rightarrow tb\tau\nu$ background.

Charged Higgs boson discovery potential at CLIC

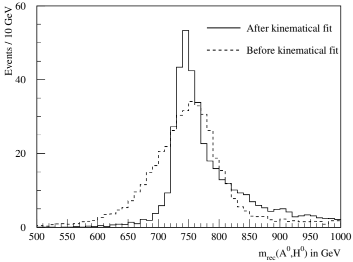


For a discovery, one requires $S \geq 10$ and $S/\sqrt{B} \geq 5$.

$e^+e^- \rightarrow A^0H^0 \rightarrow bbbb$

This decay chain has the largest branching ratio at large tan β.

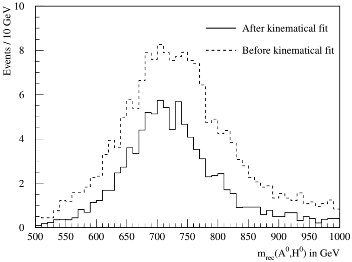
- Events with no isolated lepton and 4 b-jets,
- Assignment of two *bb* pairs to the neutral Higgs bosons,
- Mass constrained kinematical fit to improve the reconstruction.



$e^+e^- \to A^0H^0 \to tttt$

This decay chain has the largest branching ratio at small tan β.

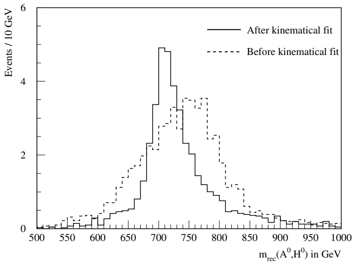
- Events with no isolated lepton, at least 12 jets, including 4 b-jets,
- Assignment of 8 non-b jets to 4 W bosons, reconstruction of 4 top quarks and assignment of *tt* pairs to the neutral Higgs bosons,
- Mass constrained kinematical fit to improve the reconstruction... Poor convergence efficiency, due to the complex event topology.



$e^+e^- \to A^0H^0 \to ttbb$

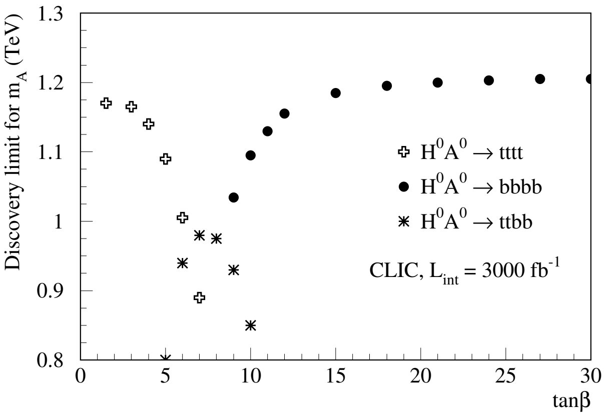
This decay chain has a significant branching ratio in the intermediate $\tan\beta$ region (around 7).

- Events with no isolated lepton, at least 8 jets including 4 b-jets,
- Assignment of the non-b jets to 2 W bosons, reconstruction of top quarks and of the neutral Higgs bosons (tt and bb),
- Mass constrained kinematical fit to improve the reconstruction.



A cut on $|\Delta m_{tb}|$ can be applied to reduce the contribution of $e^+e^- \to H^+H^- \to tbtb$ events.

Neutral Higgs boson discovery potential at CLIC



The discovery limit is set by the *bbbb* and *tttt* channels, except in the intermediate tan β region, where the *tbtb* cascade decay can also be observed.

tan β determination with charged Higgs bosons (1)

$$\frac{\Gamma(H^\pm \to tb)}{\Gamma(H^\pm \to \tau\nu)} \simeq \frac{3\Delta_{QCD}}{m_\tau^2} \times \left[\bar{m}_t^2(m_{H^\pm})\cot^4\beta + \bar{m}_b^2(m_{H^\pm})\right]$$

$$R = \frac{N_{tbtb}}{N_{tb\tau\nu}} = \frac{\epsilon_{tbtb}}{2\epsilon_{tb\tau\nu}} \times \frac{\Gamma(H^\pm \to tb)}{\Gamma(H^\pm \to \tau\nu)}$$

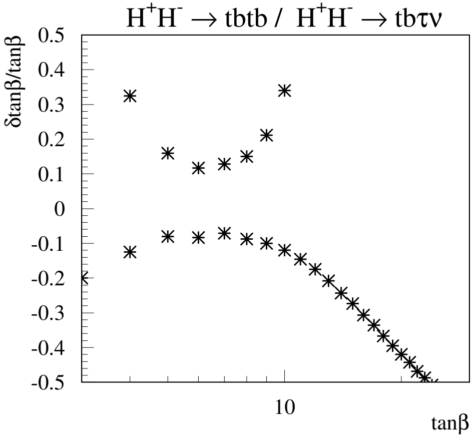
- One can determine tan β from the ratio R between the signal rates for $H^+H^- \to tbtb$ and $H^+H^- \to tb\tau\nu$.
- The result does not depend on possible other $H^\pm$ decays.
- The (statistical) error on tan β is directly derived from:

$$\frac{\Delta R}{R} = \sqrt{\left[\frac{\Delta(\sigma \times \mathrm{Br})}{\sigma \times \mathrm{Br}}\right]^2_{tbtb} + \left[\frac{\Delta(\sigma \times \mathrm{Br})}{\sigma \times \mathrm{Br}}\right]^2_{tb\tau\nu}}$$

tan β determination with charged Higgs bosons (2)

The statistical error on tan β is smallest in the 4-10 region.

- At low tan β, the signal rate for $H^+H^- \rightarrow tb\tau\nu$ is very small.
- At large tan β, the ratio R is constant.



$\tan\beta$ determination with neutral Higgs bosons (1)

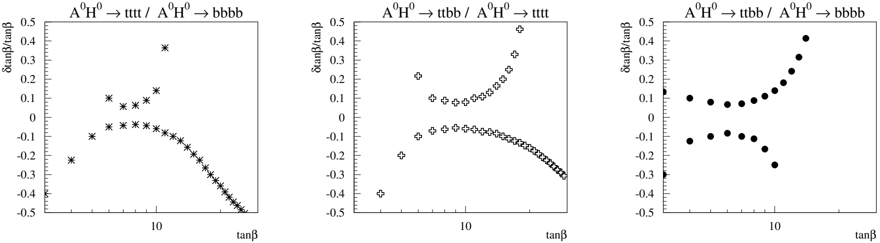
$\frac{\Gamma(H^0/A^0 \to tt)}{\Gamma(H^0/A^0 \to bb)}$ varies with $\tan\beta$ similarly to $\frac{\Gamma(H^\pm \to tb)}{\Gamma(H^\pm \to \tau\nu)}$.

- One can determine $\tan\beta$ from three ratios:
  - R^{tttt}_{bbbb} between $H^0A^0 \to tttt$ and $H^0A^0 \to bbbb$,
  - R^{ttbb}_{bbbb} between $H^0A^0 \to ttbb$ and $H^0A^0 \to bbbb$,
  - R^{tttt}_{ttbb} between $H^0A^0 \to tttt$ and $H^0A^0 \to ttbb$.
- The results do not depend on other H^0/A^0 decays.
- The (statistical) error on $\tan\beta$ is directly derived from:

$$\frac{\Delta R^1_2}{R^1_2} = \sqrt{\left[\frac{\Delta(\sigma \times \mathrm{Br})}{\sigma \times \mathrm{Br}}\right]^2_{Signal\ 1} + \left[\frac{\Delta(\sigma \times \mathrm{Br})}{\sigma \times \mathrm{Br}}\right]^2_{Signal\ 2}}$$

tan β determination with neutral Higgs bosons (2)

The statistical errors on tan β are smallest in the 4-10 region.



Conclusion and outlooks

- New simulation studies of the charged and neutral Higgs boson decays show that CLIC will be sensitive to these new particles over the whole $\tan\beta$ spectrum, for masses beyond 1 TeV.
- At CLIC, $\tan\beta$ can be measured with a good accuracy in the intermediate region (not accessible at LHC) through a comparison of the signal rates for various $H^{\pm}$ and H^0/A^0 decays.
- A study of $H^0A^0 \rightarrow tt\tau\tau/bb\tau\tau$ and a combined analysis of the charged and neutral Higgs sectors will be performed next...