UPPSALA UNIVERSITET

Heavy charged and neutral Higgs bosons at the Compact Linear Collider

Elias Coniavitis

Department of Physics and Astronomy
Uppsala University, Sweden

Spåtind 2008

Contents

UPPSALA UNIVERSITET

Introduction (1)

- Standard Model: 1 Higgs doublet for electroweak symmetry breaking → *one* neutral Higgs boson h^0
- Other theoretical models (ex. MSSM): 2 complex Higgs doublets

$$\langle\Phi_1\rangle_0 = \begin{pmatrix} v_1 \\ 0 \end{pmatrix}, \qquad \langle\Phi_2\rangle_0 = \begin{pmatrix} 0 \\ v_2 \end{pmatrix}$$

→ *five* physical states: H^+, H^-, h^0, H^0 and A^0

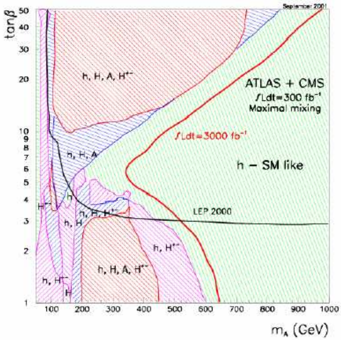
- At tree level, two independent parameters: m_A and $\tan\beta$

$$m_{H^\pm}^2 = m_A^2 + m_W^2$$

$$m_{H,h}^2 = \frac{1}{2}\left[m_A^2 + m_Z^2 \pm \sqrt{(m_A^2 + m_Z^2)^2 - 4m_A^2 m_Z^2 \cos^2 2\beta}\right]$$

Introduction (2)

Large Hadron Collider: significant but limited region of (m_A, $\tan\beta$) plane!



High-energy e+e- linear collider: improve discovery and/or precision measurements

The Compact Linear Collider

- e^+/e^- at $\sqrt{s} = 3$TeV
- Two-beam acceleration technology
- Low-energy, high-intensity drive beam parallel to the main linac $\rightarrow$ RF power for accelerating structures.
- CLIC Test Facility (CTF3) & extensive beam dynamics studies: demonstrate key tech issues by 2010.

CLIC parameters and beam-beam effects used in this study

UPPSALA UNIVERSITET

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
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}
Beamstrahlung loss	16.0	%
Coherent pairs per bunch crossing	5	10^7
$\gamma\gamma \rightarrow$ hadrons per bunch crossing	0.73	

UPPSALA UNIVERSITET

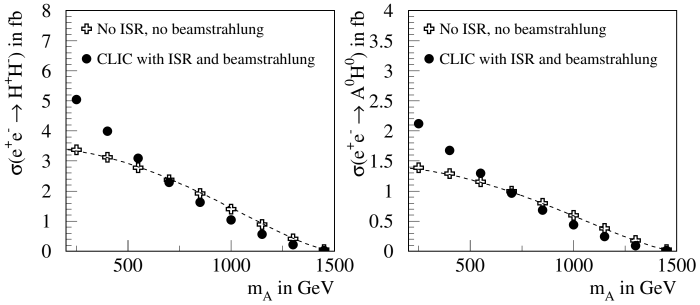
Software tools used

- HDECAY: Charged Higgs boson decay widths and branching ratios calculation
- PYTHIA 6.342: Signal generation & fragmentations. ISR, beamstrahlung, $\gamma\gamma \rightarrow$ hadrons included
- MadGraph/MadEvent: SM background generation. ISR, beamstrahlung, $\gamma\gamma \rightarrow$ hadrons included with a custom routine
- SIMDET: Fast detector simulation and event reconstruction

UPPSALA UNIVERSITET

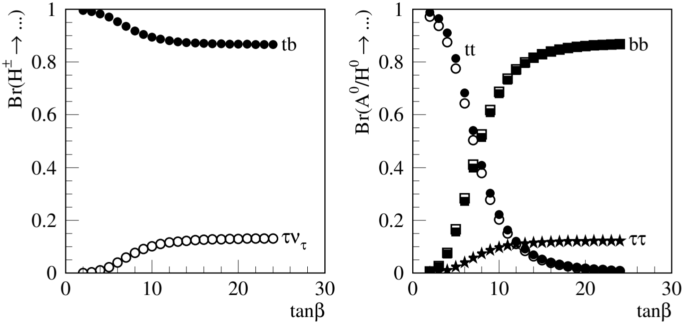
Higgs boson pair production at CLIC

Pair production: $e^+e^- \rightarrow H^+H^-$ and $e^+e^- \rightarrow A^0H^0$.



In the following, the integrated luminosity is 3000 fb^{-1}.

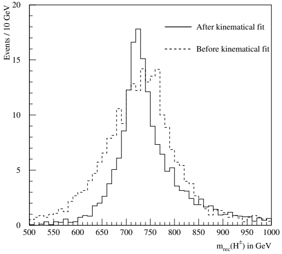
MSSM Higgs boson decays



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

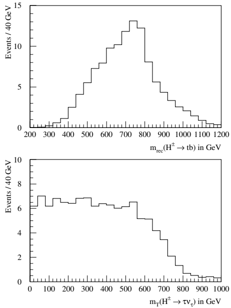
$e^+e^- \rightarrow H^+H^- \rightarrow tbtb$

- 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,
- Reduce SM $e^+e^- \rightarrow tbtb$, $bbbb$, $tttt$ background: Cuts on bb, tt and tb inv. mass
- Mass constrained kinematical fit: better reconstruction.



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

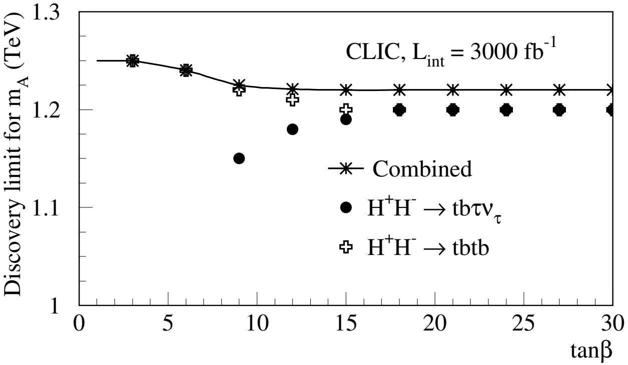
- Events with no isolated lepton, at least 5 jets including 2 b-jets and 1 τ-jet,
- Assignment of 2 non-b jets to a W boson, reconstruction of the top quark and of $H^{\pm} \rightarrow tb$,
- Transverse mass reconstruction for $H^{\pm} \rightarrow \tau\nu$.



- Reduce SM background: Cuts on missing p_T, $H^{\pm}$ transverse mass and transverse angle between $H^{\pm}$ candidates

Charged Higgs boson discovery potential at CLIC

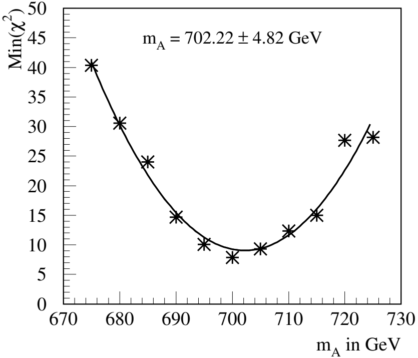
For discovery, we require $S \geq 10$ and $S/\sqrt{B} \geq 5$.



UPPSALA UNIVERSITET

Accurate mass measurement

- χ^2 fit on $H^+H^- \rightarrow tbtb$ (+ background) sample to determine $H^{\pm}$ mass (and thereby m_A)
- Obtained relative uncertainties for $m_{H^{\pm}}$ typically <1%



	m_A (GeV)	δm_A (GeV)
Small tan β	697.4	3.7
Large tan β	702.2	4.8

The real mass m_A is 700 GeV and $\mathcal{L} = 3000$ fb^{-1}.

Determination of $\tan\beta$ (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 $\tan\beta$ from the ratio between the signal rates for $H^+H^- \to tbtb$ and $H^+H^- \to tb\tau\nu$.
- The (statistical) error on $\tan\beta$ is can be obtained from:

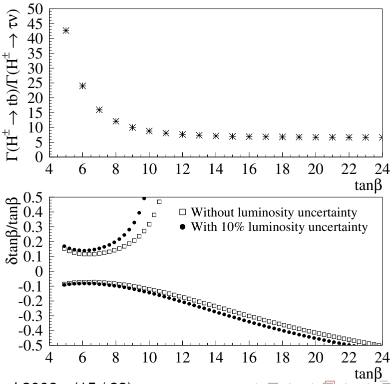
$$\frac{\Delta R}{R} = \sqrt{\left[\frac{\Delta(\sigma \times \mathrm{Br})}{\sigma \times \mathrm{Br}}\right]^2_{tbtb} + \left[\frac{\Delta(\sigma \times \mathrm{Br})}{\sigma \times \mathrm{Br}}\right]^2_{tb\tau\nu}}$$

UPPSALA UNIVERSITET

Determination of tan β (2)

The statistical error on tan β is smallest in the 5-10 region:

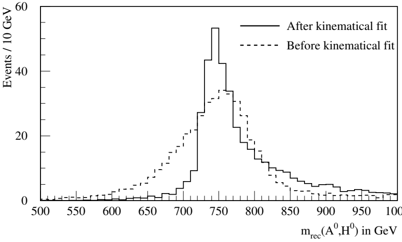
- Low tan β: the signal rate for $H^+H^- \rightarrow tb\tau\nu$ is small.
- Large tan β: the ratio R is constant.



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

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

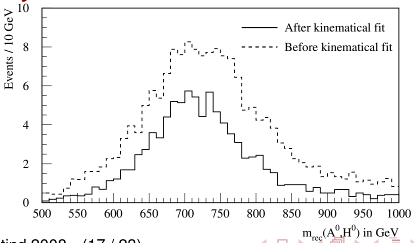
- Events with no isolated lepton and 4 b-jets,
- Assign two *bb* pairs to the neutral Higgs bosons,
- Reduce background: Cuts on hardest jets' energy and reconstructed Higgs mass
- Mass constrained kinematical fit to improve the reconstruction.



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

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

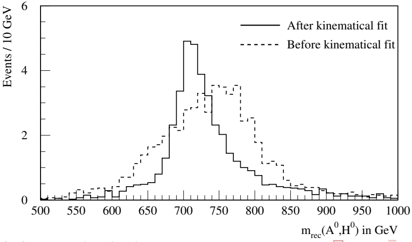
- Events with no isolated lepton, at least 12 jets with 4 b-jets,
- Reconstruct 4 W bosons, 4 top quarks; two neutral Higgs bosons,
- Reduce background: Cuts on reconstructed W, top and Higgs masses
- Complex event topology: Poor convergence efficiency of the mass constrained kinematical fit.



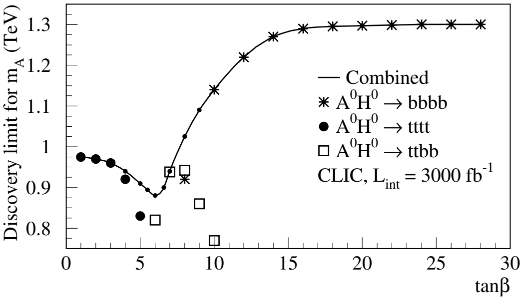
$e^+e^- \rightarrow A^0H^0 \rightarrow ttbb$

This decay has a significant branching ratio for tan $\beta \simeq 7$.

- Events with no isolated lepton, at least 8 jets with 4 b-jets,
- Assign the non-b jets to 2 W bosons, reconstruct top quarks and neutral Higgs bosons (*tt* and *bb*),
- Reduce background: Cuts on reconstructed W, top and Higgs masses,
- Mass constrained kinematical fit to improve the reconstruction.



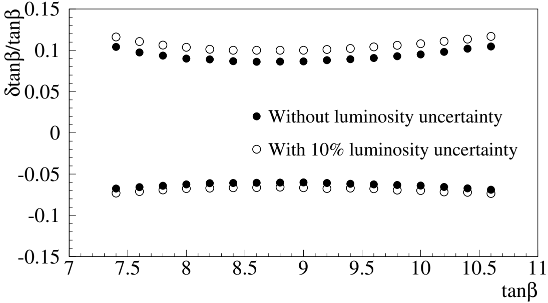
Neutral Higgs boson discovery potential at CLIC



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

Determination of tan β

Ratio R^{ttbb}_{bbbb} between $H^0A^0 \to ttbb$ and $H^0A^0 \to bbbb$: best determination of tan β



Summary and conclusions

- Simulation studies of charged and neutral Higgs bosons show that CLIC is sensitive to H^+H^- and H^0A^0 pairs over the whole tan β spectrum, for masses up to and beyond 1 TeV.
- At CLIC, tan β can be determined in the intermediate region (not accessible at LHC) with a good accuracy, through the measurement of the signal rates for $H^{\pm}$ and H^0/A^0 decays.
- For more details:
  E. Coniavitis & A. Ferrari, Phys. Rev. D75 (2007) 015004.

UPPSALA UNIVERSITET

Backup slides

Backup slide: χ^2 analysis

- χ^2 fit on tbtb sample to determine $H^{\pm}$ mass.
- Compare a sample of *data* events to various large samples of *simulated* events, normalized to 3000 fb^{-1}, using:

$$\chi^2 = \sum_i \frac{(N_r(i) - N_s(i))^2}{N_r(i)}.$$

- For each mass, the number of *simulated* events is first adjusted to minimize χ^2. Then, Min(χ^2) is plotted as a function of the *simulated* mass parameter m_A, in order to find the value that maximizes the likelihood function.
- Note that some $A^0 H^0$ pairs may also be found in the *data* event samples, but they do not significantly affect the mass determination.