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SENSITIVITY STUDY FOR CHARGED AND NEUTRAL MSSM HIGGS BOSONS AT CLIC

Arnaud Ferrari

Department of Nuclear and Particle Physics
Uppsala University, Sweden

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MSSM HIGGS BOSONS AT CLIC

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Contents

Introduction

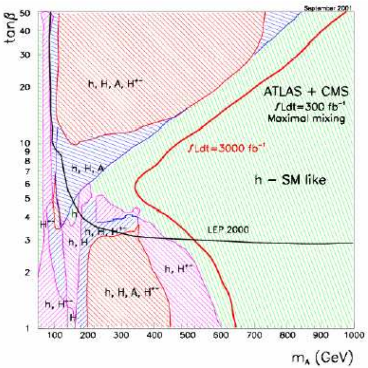
- In the Standard Model, one doublet of Higgs scalars is responsible for the electroweak symmetry breaking and there is only one neutral Higgs boson h^0.
- Other theories, e.g. MSSM (Minimal Supersymmetric extension of the Standard Model), predict 2 complex Higgs doublets $\rightarrow$ 5 states: H^+, H^-, h^0, H^0, A^0.
- At tree level, the MSSM Higgs sector is determined by two independent parameters: m_A and $\tan\beta$.

We examine the prospects for the discovery of charged and neutral MSSM Higgs bosons and the measurement of their properties at CLIC.

More details in:
E. Coniavitis & A. Ferrari, Phys. Rev. D75 (2007) 015004.

MSSM Higgs bosons at LHC

The Large Hadron Collider should discover some of the MSSM Higgs bosons, but only in a limited region of the $(m_A, \tan\beta)$ plane!



A high-energy e+e- linear collider will therefore be needed to improve the discovery and/or precision measurements.

CLIC beam parameters at 3 TeV

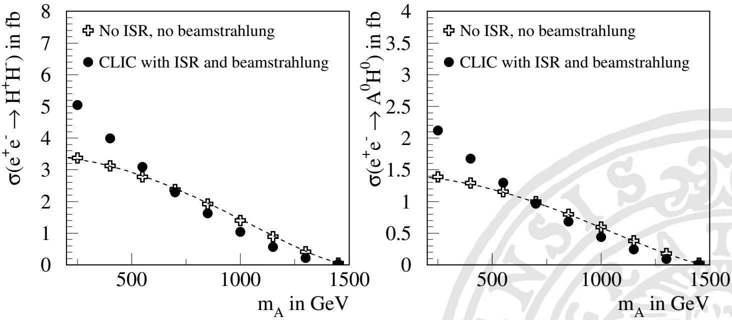
Center-of-mass energy	3	TeV
Main linac RF frequency	30	GHz
Accelerating gradient	150	MV/m
Linac and site lengths	28/33.2	km
Linac repetition rate	150	Hz
No. of bunches per pulse	220	
No. of particles per bunch	2.56	10^9
Bunch spacing	0.267	ns
Primary beam power	20.4	MW
Total site AC power	418	MW
Wall 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	

Monte-Carlo simulation study tools

- 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 and $\gamma\gamma \rightarrow$ hadrons) are included.
- The physics background events are generated with MadEvent & MadGraph. A home-made routine was written to include the CLIC beam-beam effects and PYTHIA is used for the fragmentation of the quarks.
- Fast detector simulation + event reconstruction with SIMDET, 70% tagging efficiency for b and τ jets.

MSSM Higgs boson pair production at CLIC

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



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

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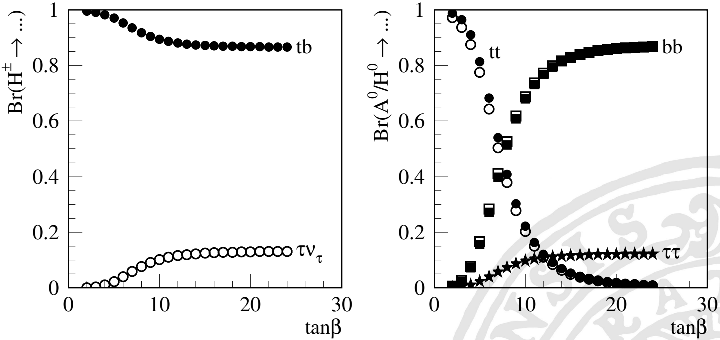
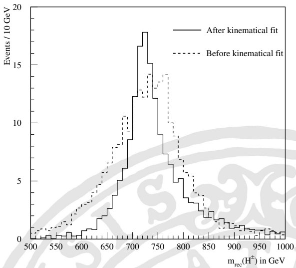
MSSM Higgs boson decays



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

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

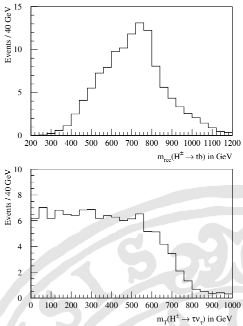
- Events with no isolated lepton, at least 8 jets including 4 b-jets,
- Assignment of the non-b jets to 2 W bosons, reconstruction of top quarks and of the charged Higgs bosons,
- Mass constrained kinematical fit: better reconstruction.



Various cuts on the *bb*, *tt* and *tb* systems are then applied to reduce the $e^+e^- \to tbtb$, *bbbb*, *tttt* backgrounds.

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

- 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 $H^\pm \to tb$,
- Transverse mass reconstruction for $H^\pm \to \tau\nu$.



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

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Introductory slides

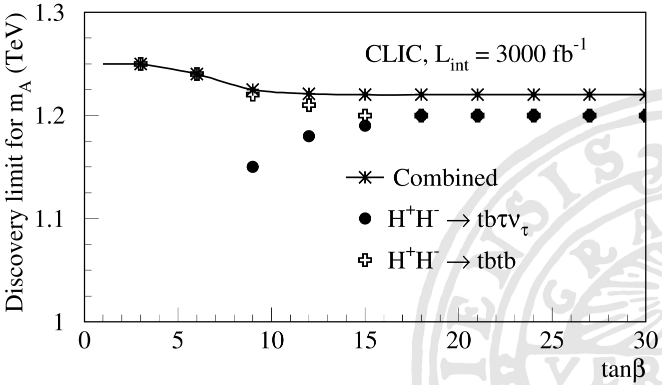
Study of the charged Higgs sector

Study of the neutral Higgs sector

Summary and conclusions

Charged Higgs boson discovery at CLIC

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



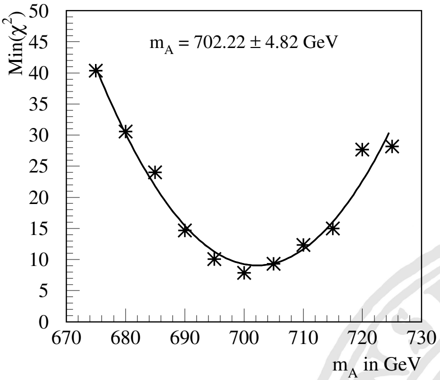
Accurate mass measurement (1)

- The charged Higgs boson mass (and thereby m_A) can be accurately determined with a χ^2-analysis.
- Compare a sample of *data* events to various large samples of *simulated* events normalized to 3 ab^{-1}:

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

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

Accurate mass measurement (2)



Configuration	m_A (GeV)	δm_A (GeV)
Small tan β with A^0H^0	697.4	3.7
Small tan β without A^0H^0	701.2	3.7
Large tan β with A^0H^0	702.2	4.8
Large tan β without A^0H^0	701.8	4.9

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

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Determination of tan β (1)

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

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

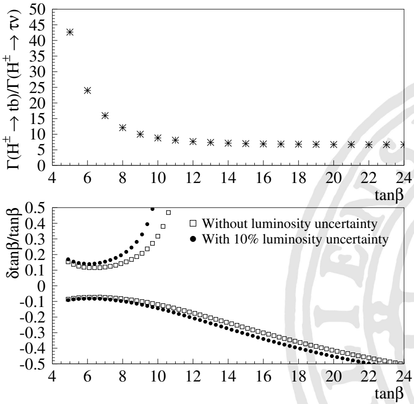
- One can determine tan β from the ratio between the signal rates for $H^+H^- \to tbtb$ and $H^+H^- \to tb\tau\nu$.
- The (statistical) error on tan β is directly derived from:

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

Determination of tan β (2)

The statistical error on tan β is smallest in the 4-10 region ($+11.4\%$ and -6.7%).

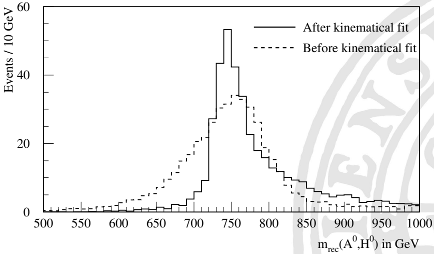
- Low tan β: the signal rate for $H^+H^- \to tb\tau\nu$ is small.
- Large tan β: the ratio R is constant.



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

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

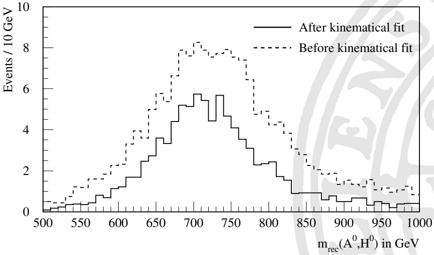
- Events with no isolated lepton and 4 b-jets,
- Assign two *bb* pairs to the neutral Higgs bosons,
- Mass constrained kinematical fit to improve the reconstruction.



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

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

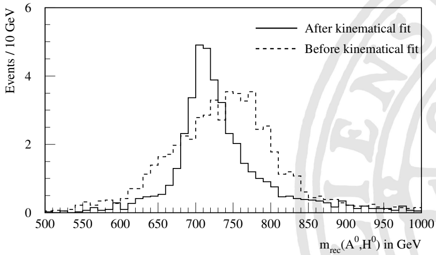
- Events with no isolated lepton, at least 12 jets with 4 b-jets,
- Assign 8 non-b jets to 4 W bosons, reconstruct 4 top quarks, assign *tt* pairs to the neutral Higgs bosons,
- Poor convergence efficiency of the mass constrained kinematical fit, due to the complex event topology.



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

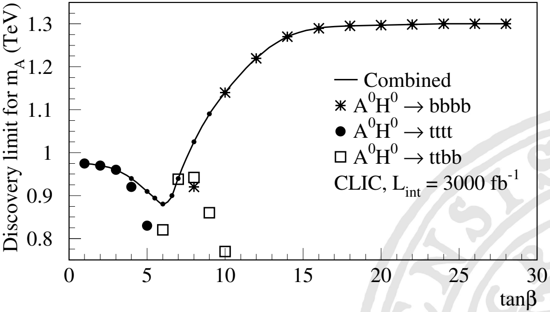
This decay has a significant branching ratio for $\tan\beta \simeq 7$.

- 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*),
- Mass constrained kinematical fit to improve the reconstruction.



Neutral Higgs boson discovery at CLIC

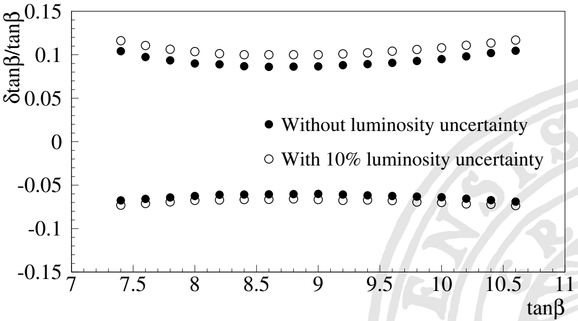
Specific cuts must be applied in order to reduce the contribution of $e^+e^- \to H^+H^- \to tbtb$ events.



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

Determination of tan β

One can best determine tan β from the ratio R^{ttbb}_{bbbb} between $H^0A^0 \rightarrow ttbb$ and $H^0A^0 \rightarrow bbbb$.



Summary and conclusions

- Simulation studies of charged and neutral MSSM Higgs bosons show that CLIC is sensitive to H^+H^- and H^0A^0 pairs over the whole $\tan\beta$ spectrum, for masses up to and beyond 1 TeV.
- At CLIC, $\tan\beta$ 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.
- A linear collider is required in order to go beyond the LHC discoveries: explore new regions of the MSSM parameter space and/or precision measurements.