Search for the MSSM Higgses in the intense-coupling regime at a Linear Collider (TESLA)

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Outline

• Introduction
• What is the intense-coupling regime?
• Search at the LHC
• Results for LC
• Concluding Remarks

Simulations done by means of FeynHiggs for parameters;
HDECAY for Brs and widths;
CompHEP for cross sections, distributions, event generation with ISR and Beamstrahlung;
CompHEP-PYTHIA interface and PYTHIA - for FSR and hadronization;
SIMDET for a detector response
A firm prediction of MSSM: 5 Higgs boson states
two CP–even $h$ and $H$
pseudoscalar $A$ and two charged $H^\pm$ bosons
At least the lightest Higgs boson $h$ must have a mass below some value of
$130 – 135$ GeV
In the decoupling regime $H, A$ and $H^\pm$ are heavy $M_A \sim M_H \sim M_{H^\pm}$
The lightest Higgs particle $h$ is similar to the SM Higgs
Another, more complex, situation is when pseudoscalar $A$ boson is not
much larger than $h$, and $\tan \beta$ is large.
Masses could be rather close.
Widths are large.
Couplings and Br-fractions in some cases are significantly different from
SM or decoupling regime.
So, the phenomenology is different.
Such a scenario was called the Intense-coupling regime
(E.B., A.Djouadi, M.Mühlleitner, A.Vologdin)
The masses of the MSSM Higgs bosons (left) and the normalized couplings of the CP-even Higgs bosons to vector bosons and third-generation quarks (right) as a function of $M_A$ and $\tan \beta = 30$. For the $b$-quark couplings, the values $10 \times g_{\Phi bb}^{-2}$ are plotted.
Total Width and Branching Fractions

\begin{figure}
\centering
\includegraphics[width=\textwidth]{total_width_and_branching_fractions}
\end{figure}
How to resolve?

At the LHC:

$\text{Br}(h, H, A \rightarrow \gamma\gamma) \sim 10^{-5} - 10^{-6}$ - too small

$b\bar{b}$ and $\tau^+\tau^-$ modes - energy resolution is not enough

More promising - $\mu^+\mu^-$ Higgs decay in $b\bar{b} + h, H, A$ production:

$\text{Br}(h, H, A \rightarrow \mu^+\mu^-) \sim 3 - 3.5 \times 10^{-4}$, Energy resolution for muons

$\sim 1 - 1.5 \text{ GeV}$, Tagging b-jets

At LC a multichannel analysis should be used:

1. $b\bar{b}l^+l^-$ mode using recoil mass for the Higgsstrahlung
2. $b\bar{b}b\bar{b}$ and/or $b\bar{b}\tau^+\tau^-$ modes for the Higgs pair production
\(\mu^+ \mu^-\) pair invariant mass distributions at the LHC for the signal before and after detector resolution smearing (left) and for the signal and the background (right) for P1, P2 and P3 parameter points. (E.B., A.Djouadi, A.Nikitenko)
Main processes at LC to search for MSSM intense coupling Higgses:

Zh, ZH, Ah, AH

Mostly interesting signatures after examining various possibilities:

\[ Zh, ZH \rightarrow l^+ l^- b\bar{b} \]

\[ Ah, AH \rightarrow b\bar{b}b\bar{b} \]

All simulations for the colliding energy 300 and 500 GeV integrated luminosity 500 and 1000 \( fb^{-1} \)

Analysis in the decoupling regime (only two Higgses are closed in masses) - K.Desch, T.Kljmkovich, T.Kuhl, A.Raspereza

Strategy

- Reciol Z mass technique in the \( l^+ l^- b\bar{b} \) sample. Only h and H contribute
- 4 b-jet sample. ”Combinatorial mass difference method” to extract A-boson mass using the measured h and H masses
Basic cross sections for all the tree MSSM points P1, P2, P3

\begin{align*}
\text{\textbf{\(e^- e^+ \rightarrow Z h\)}} & \quad \text{\textbf{\(e^- e^+ \rightarrow Z H\)}} \\
\text{\textbf{\(e^- e^+ \rightarrow A h\)}} & \quad \text{\textbf{\(e^- e^+ \rightarrow A H\)}} 
\end{align*}
Recoil mass in the llbb sample at 300 GeV LC
If no cuts and no b-tagging is applied:

\[ e^+e^- \to Z^0, b, \bar{b} \]

The small Higgs is not resolved.
The backgrounds here are 4-fermion backgrounds (CompHEP+PYTHIA):
\[ l^+l^- + 2 \text{ b jets} \quad l^+l^- + 2 \text{ light jets} \]
b-tagging and simple cuts

- $M_{l^+ l^-} = 90 \pm 6 \text{ GeV}$
- $E_j \geq 12 \text{ GeV}$
- $\theta(j_1, j_2) \geq 95 \text{ grad}$
- only 2 jets

Efficiencies:

- for the signal 68%
- for $l^+ l^- \bar{b}\bar{b}$ background 22%
- for $l^+ l^- c\bar{c}$ background 6.4%
- for $l^+ l^- + 2$ background light jets 0.1%
Recoil mass in the Z\_bb sample at 300 GeV LC

\[ e^+ e^- \rightarrow Z^0, b, \bar{b} \]

**P1**

- \( M_h = 124.43 \pm 0.28 \) GeV
- \( M_H = 135.25 \pm 0.08 \) GeV

**P2**

- \( M_h = 127.62 \pm 0.18 \) GeV
- \( M_H = 135.49 \pm 0.11 \) GeV

**P3**

- \( M_h = 130.11 \pm 0.09 \) GeV
- \( M_H = 138.54 \pm 0.17 \) GeV
Masses of the h and H Higgses could be extracted with an accuracy of about 80-280 MeV at 300 GeV collider with 500 $fb^{-1}$ (about 50-70 MeV for the SM Higgs mass. See TDR)
Recoil mass technique in the llbb sample at 500 GeV LC works worse

- cross section is smaller
- energy resolution for higher momentum leptons from moving faster Z boson is worse
- ISR influence is larger

Only the signal at 500 GeV with even $1000 \, fb^{-1}$

It is problematic to resolve the peaks
At the next step

Ah, $AH \rightarrow b\bar{b}b\bar{b}$

The irreducible backgrounds to Higgs pair production include now 4b SM backgrounds from all the possible contributions

$Zh, \ ZH \rightarrow b\bar{b}b\bar{b}$

All three Higgses contribute but masses of h and H are already known

Combinatorial mass difference method is used in the 4 b-jet event sample to extract the A-boson mass
The 4 b-jet sample at 300 GeV LC

$e^+e^- \rightarrow b, \bar{b}, b, \bar{b}$

**P1**

$M_A = 125.43 \pm 0.31 \text{ GeV}$

**P2**

$e^+e^- \rightarrow b, \bar{b}, b, \bar{b}$

$M_A = 129.92 \pm 0.24 \text{ GeV}$

**P3**

$e^+e^- \rightarrow b, \bar{b}, b, \bar{b}$

$M_A = 133.56 \pm 0.26 \text{ GeV}$
Conclusions

- The intense coupling regime - one of the most difficult scenario to be resolved completely
  (At the LHC - one can separate states if mass differences are about 5 GeV or more)
- At LC - h and H masses could be measured to about 80-280 MeV accuracy at energies about 300 GeV and 500 $fb^{-1}$ lumi in the 2 leptons + 2 b-jets mode using the recoil mass technique
- Mass of the A Higgs bosons can be measured to a similar accuracy in the 4 b-jet mode (Ah+AH) using measured values $M_h$ and $M_H$ and applying the ”combinatorial mass difference” analysis
- This is a first ”semi-theoretical” analysis. There are many missing things which remain to be done: other irreducible backgrounds; optimization of cuts and a search strategy; better methods like Nueral Networks; $b\bar{b}\tau^+\tau^-$ channel may be using tau polarization to discriminate (h,H) and A bosons; the threshold scan etc.