Single heavy MSSM Higgs boson production at a Linear Collider

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Based on T. Farris, J. Gunion, & H.L., hep-ph/0202087
H.L. & S. Su, hep-ph/0203270
and work in progress.

Introduction

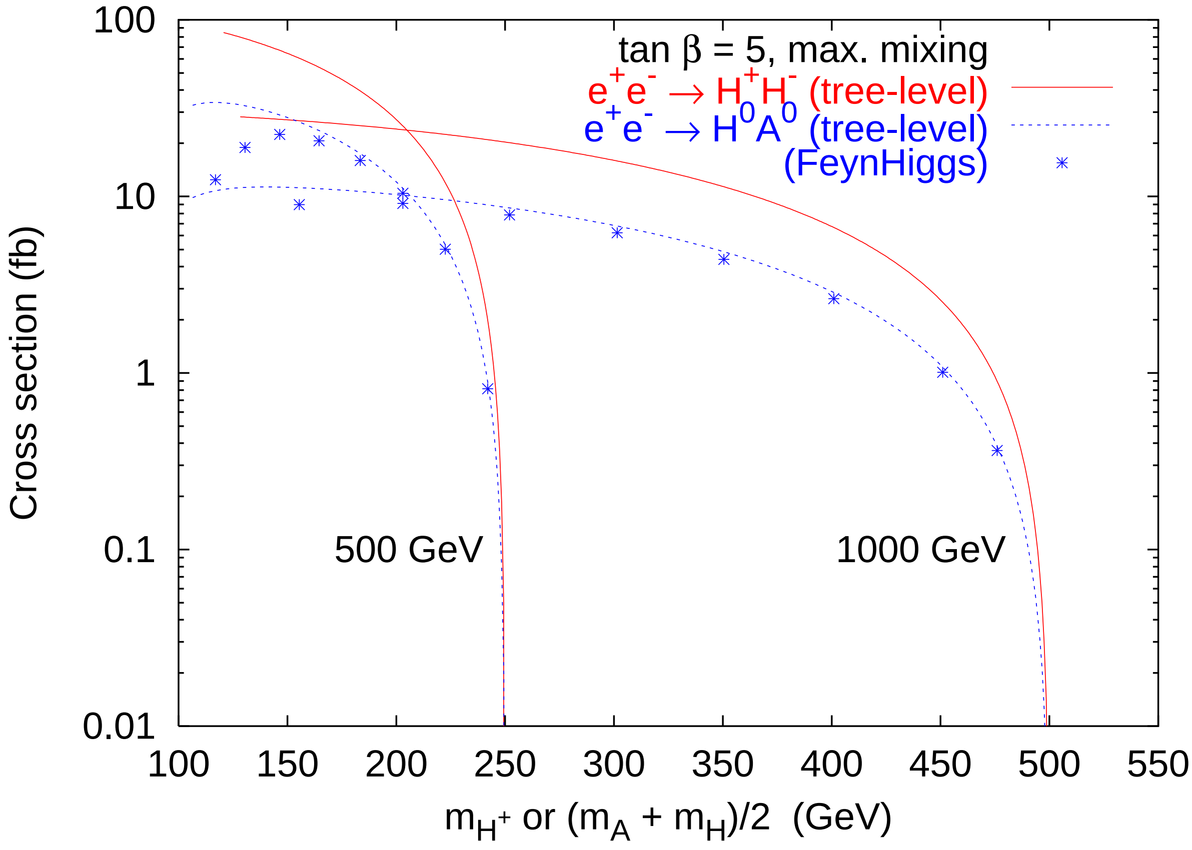
Measurements of the properties of the heavy Higgs bosons H^0, A^0 and $H^\pm$ of the MSSM can tell us a lot about the MSSM parameters.

- Heavy Higgs masses:
  - The overall mass scale m_A or $m_{H^\pm}$ is an important MSSM parameter.
  - The MSSM predicts distinctive mass relations between m_A, m_H and $m_{H^\pm}$. [C.-P. Yuan's talk]
- Heavy Higgs couplings probed, *e.g.*, in decays:
  - Couplings to fermions are sensitive to $\tan\beta$ and to potentially large SUSY radiative corrections to Yukawa couplings.
  - Couplings to sfermions (if kinematically accessible) may be sensitive to A-terms.
- Non-decoupling:
  - Even with LC precision, the light Higgs h^0 becomes indistinguishable from the SM Higgs even at the 2σ level typically for $m_A \gtrsim 600$ GeV [Carena et al; Battaglia et al]; $\rightarrow$ sensitivity to MSSM parameters from its couplings is lost.
  - For the heavy Higgs bosons there is no loss of sensitivity to MSSM parameters due to decoupling.

When kinematically allowed, the dominant production mechanisms for the heavy MSSM Higgs bosons at an e^+e^- collider are

$$e^+e^- \to H^+H^- \qquad \text{and} \qquad e^+e^- \to H^0A^0.$$

These are only useful for heavy Higgs masses below half the center-of-mass energy of the collider.



How to access higher masses?

→ Single heavy Higgs boson production

Review of the literature

A number of single heavy Higgs production modes have been considered.

e^+e^- collisions:

- $e^+e^- \to ZH^0$, h^0A^0 [FeynHiggsXS: Heinemeyer et al]
- $e^+e^- \to \nu\bar{\nu}H^0$
- $e^+e^- \to b\bar{b}H^0$, $b\bar{b}A^0$ [Gutierrez-Rodriguez et al; Cotti et al]
- $e^+e^- \to \tau^-\bar{\nu}H^+$, $\bar{t}bH^+$ [Kanemura et al; Gutierrez-Rodriguez et al]
- $e^+e^- \to ZA^0$, γA^0 [Akeroyd et al; Djouadi et al]
- $e^+e^- \to W^+H^-$ [Arhrib et al; Kanemura; Zhu; Logan et al]
- $e^+e^- \to \nu\bar{\nu}A^0$ [Farris et al]

$e^-\gamma$ collisions:

- $e^-\gamma \to \nu H^-$ [Kanemura et al]

$\gamma\gamma$ collisions:

- $\gamma\gamma \to \tau^-\bar{\nu}H^+$ [He et al]
- $\gamma\gamma \to H^0$, A^0 [Gunion et al; Mühlleitner et al; Asner et al]
- $\gamma\gamma \to W^+H^-$ [Zhou et al]

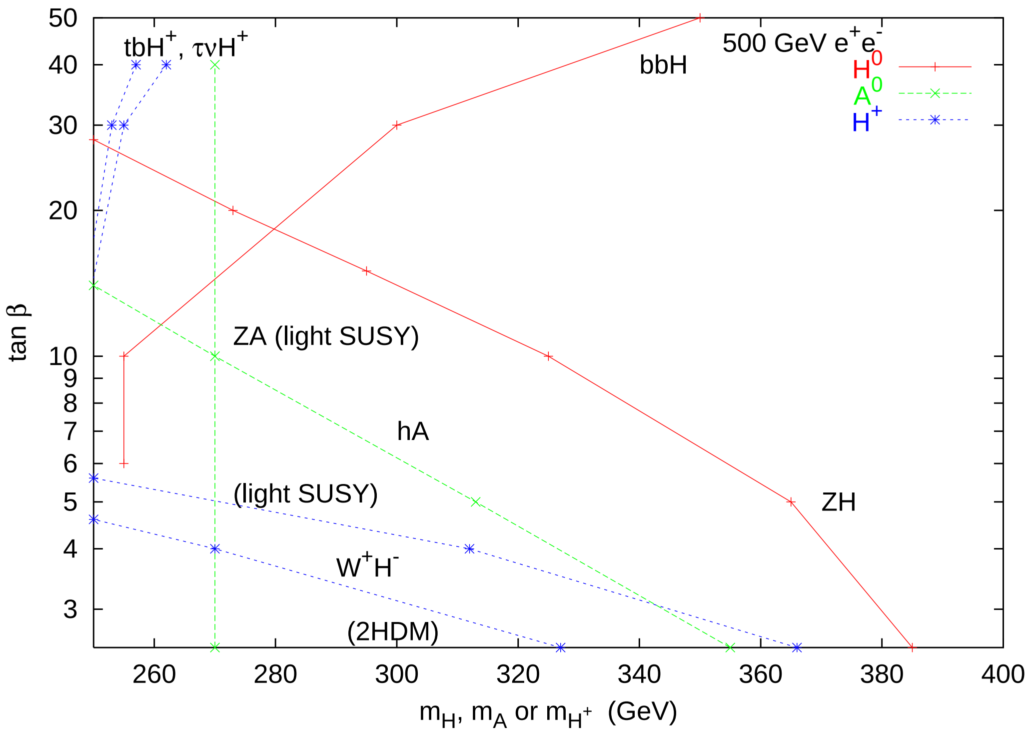
For most of these single heavy Higgs production modes, no signal/background analyses or experimental studies have been done.

To compare the various modes, we look at areas where 10 or more signal events would be produced in the LC data sample.

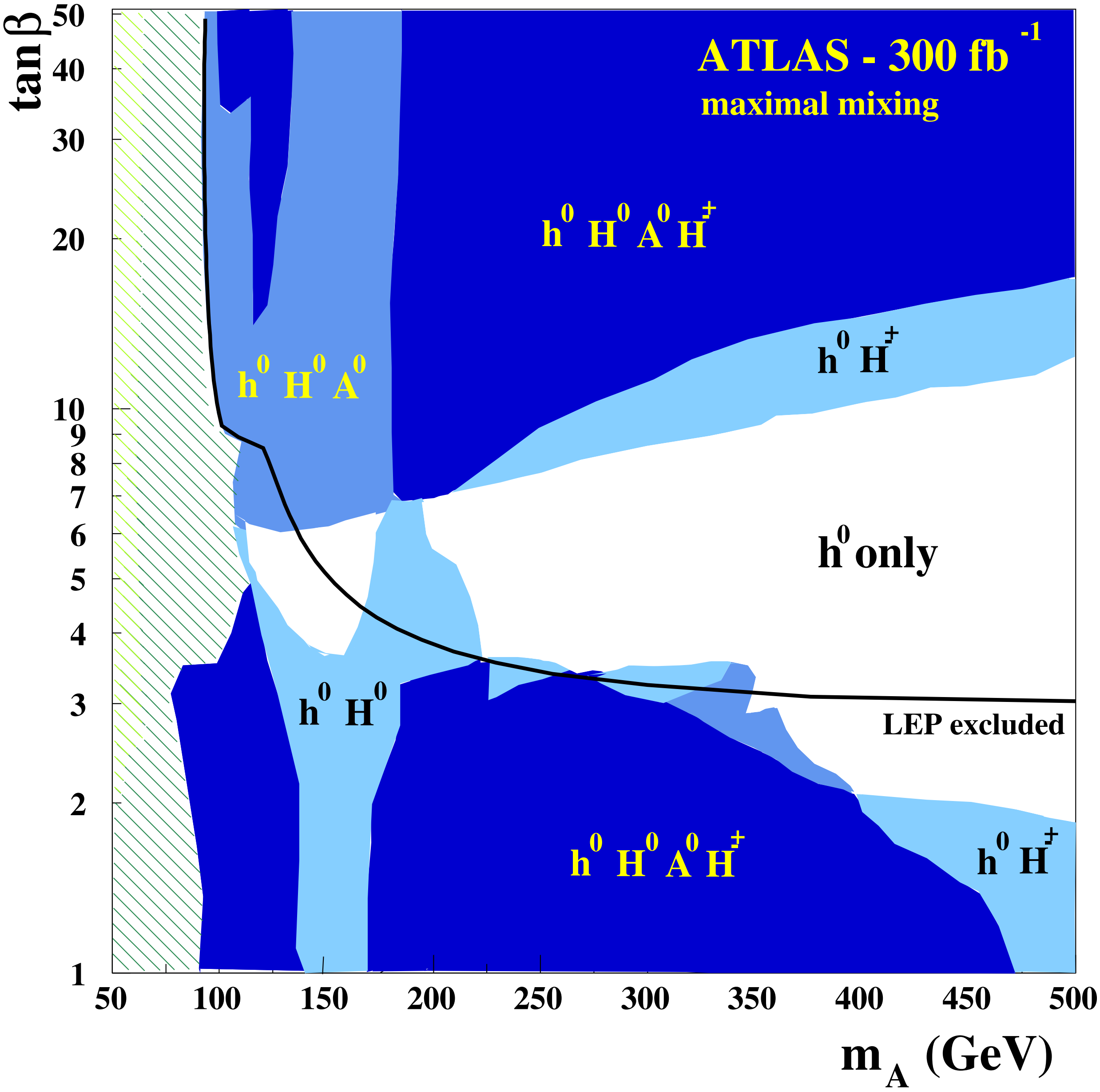
- 500 fb^{-1} at 500 GeV $\rightarrow \sigma = 0.02$ fb gives 10 events.

- 1000 fb^{-1} at 1000 GeV $\rightarrow \sigma = 0.01$ fb gives 10 events.

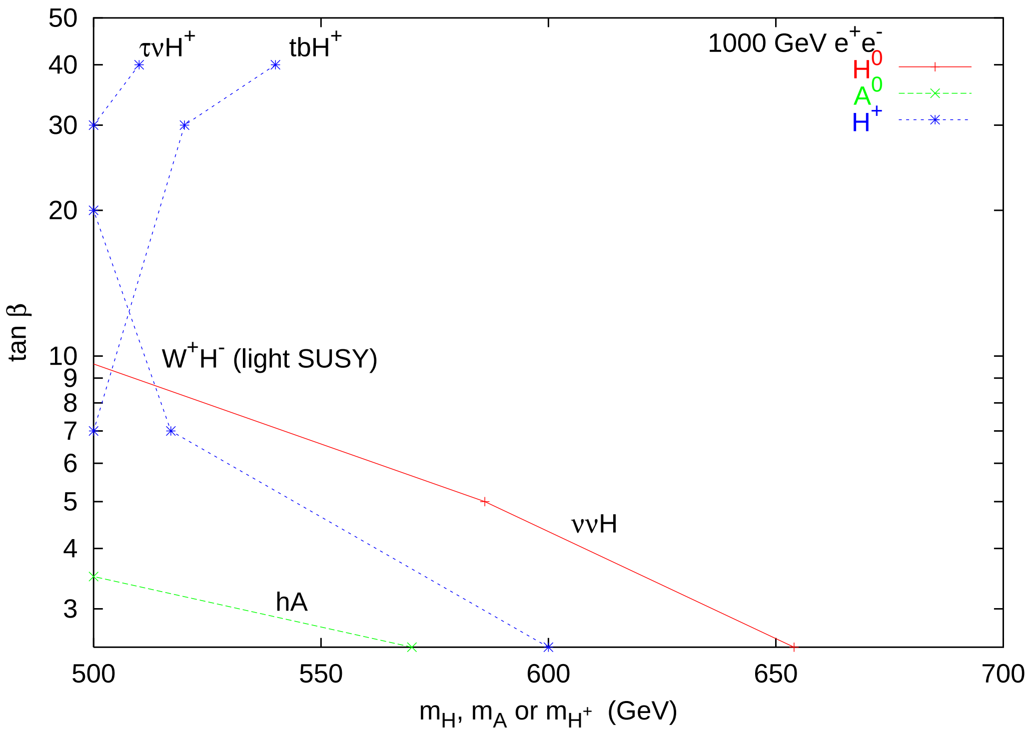
Focus on Higgs masses above $\sqrt{s}/2$:



Too small to see: $\nu\bar{\nu}H^0$, $b\bar{b}A^0$, γA^0, $\nu\bar{\nu}A^0$



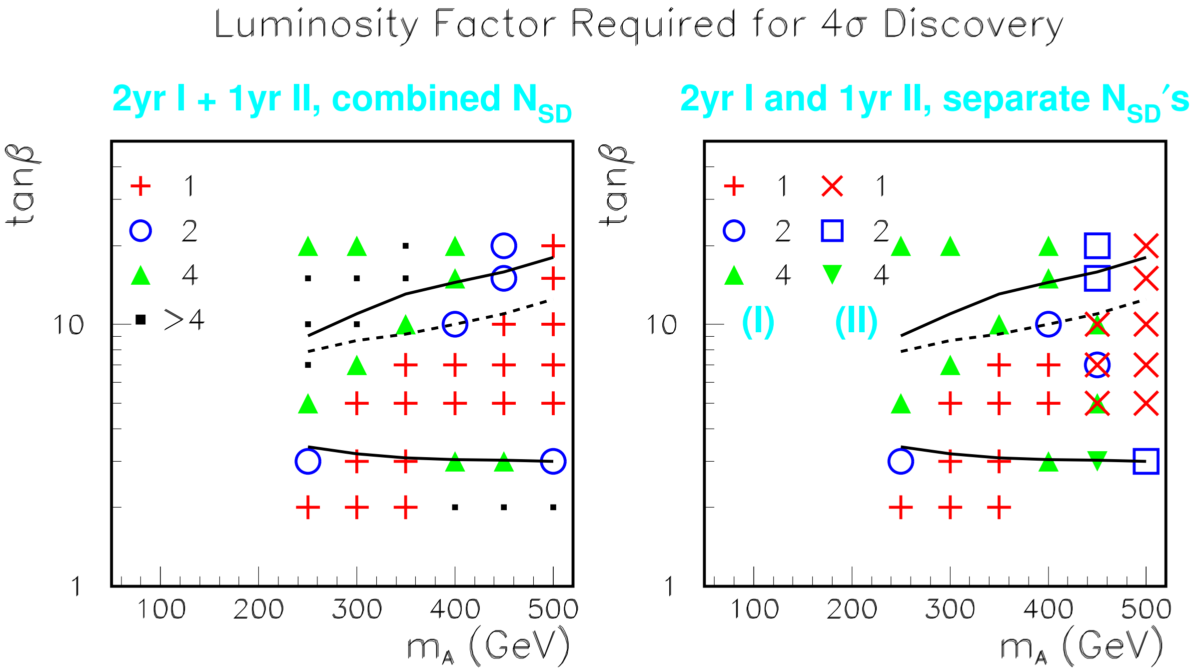
ATLAS - 300 fb^{-1}
maximal mixing
h^0 H^0 A^0 $H^\pm$
h^0 $H^\pm$
h^0 H^0 A^0
h^0 only
h^0 H^0
LEP excluded
h^0 H^0 A^0 $H^\pm$
h^0 $H^\pm$
tanβ
m_A (GeV)



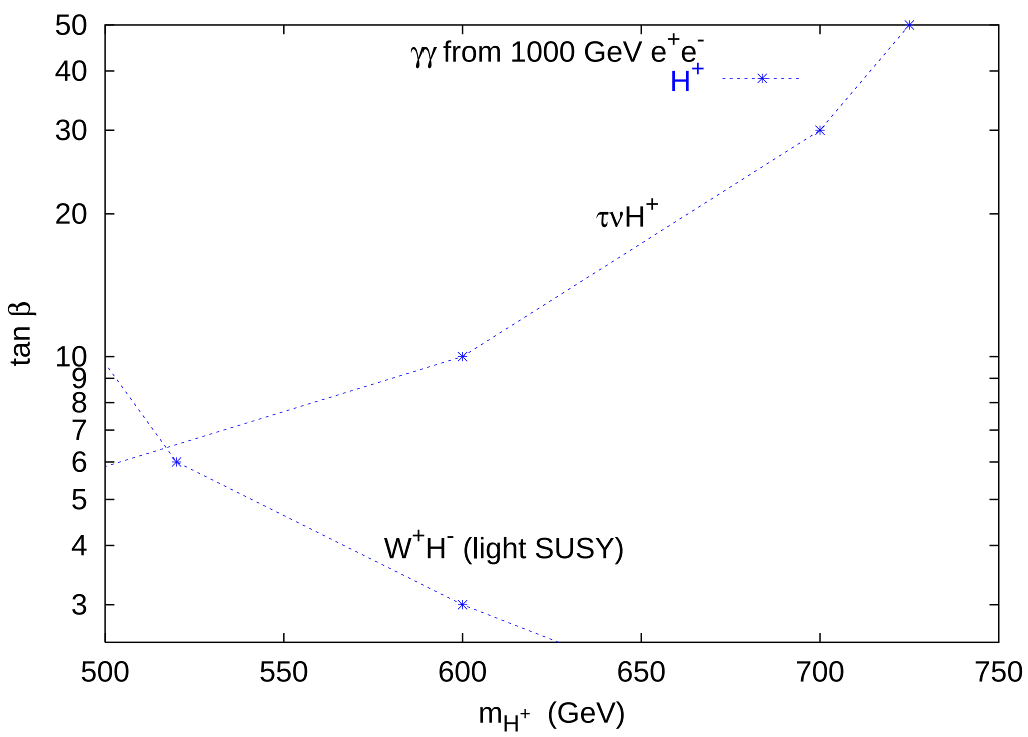
Too small to see: ZH^0, $b\bar{b}H^0$, $b\bar{b}A^0$, ZA^0, γA^0, $\nu\bar{\nu}A^0$

$e^-\gamma \to \nu H^-$ in the 2HDM is too small to be seen in the expected $e^-\gamma$ luminosity (~ 100 fb^{-1}).

$\gamma\gamma$ collisions:
s-channel H^0, A^0 production [from Asner et al, hep-ph/0110320]
$\sqrt{s_{ee}} = 630$ GeV



Other modes: (assumes 1000 fb^{-1} of e^+e^- luminosity devoted to $\gamma\gamma$ collisions)



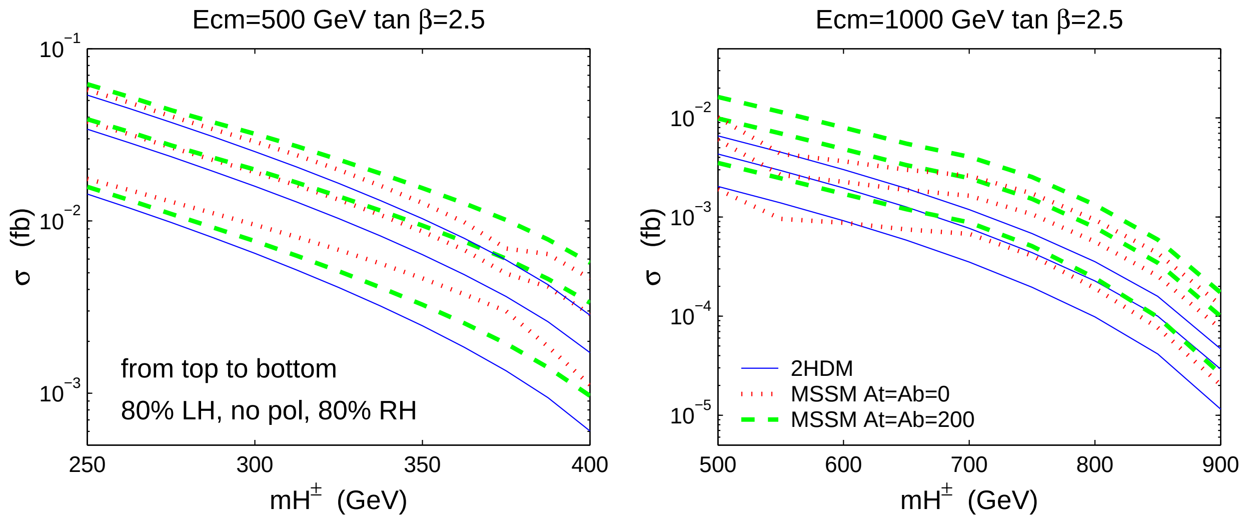
$e^+e^- \rightarrow W^+H^-$

In Higgs sectors containing only SU(2) doublets and/or singlets, there is no W^+H^-Z or $W^+H^-\gamma$ coupling at tree level, so this process first occurs at the one-loop level.

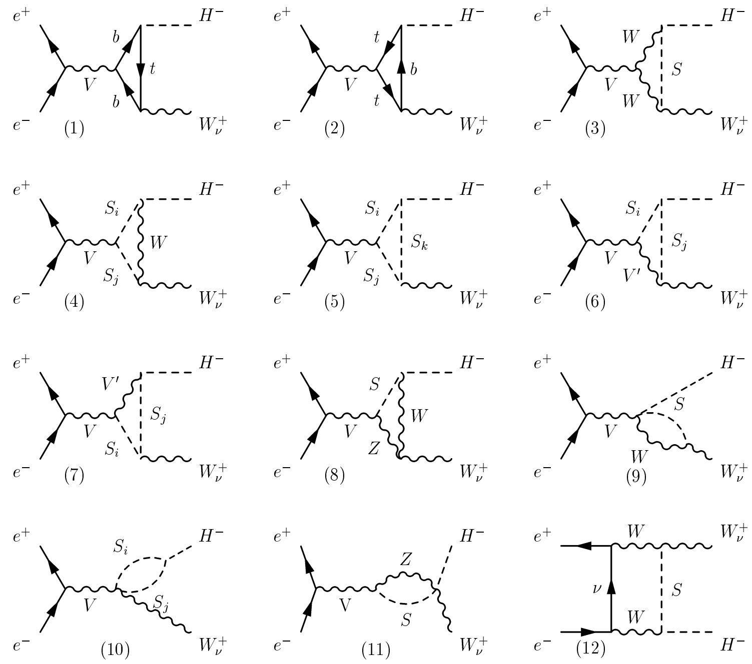
- Computed in the (non-supersymmetric) two Higgs doublet model in A. Arhrib *et al.*, NPB 581, 34 (2000)
- Full MSSM calculation done in H.L. & S. Su, hep-ph/0203270

For light enough SUSY masses ($\sim$ 200 GeV), the SUSY contributions can increase the production cross section significantly.

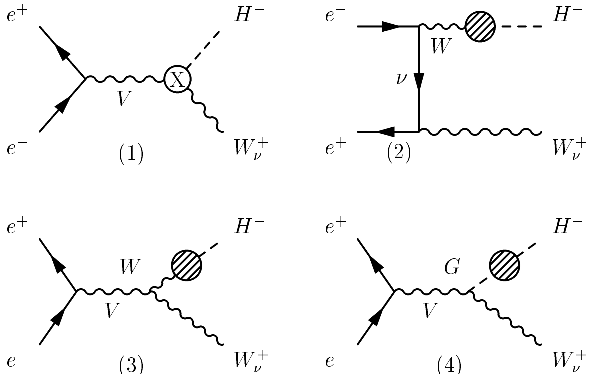
Left-polarized e^- beams also increase the cross section. Plots show 80% LH, unpolarized, and 80% RH e^- beams. The e^+ beams are assumed to be unpolarized.



2HDM:

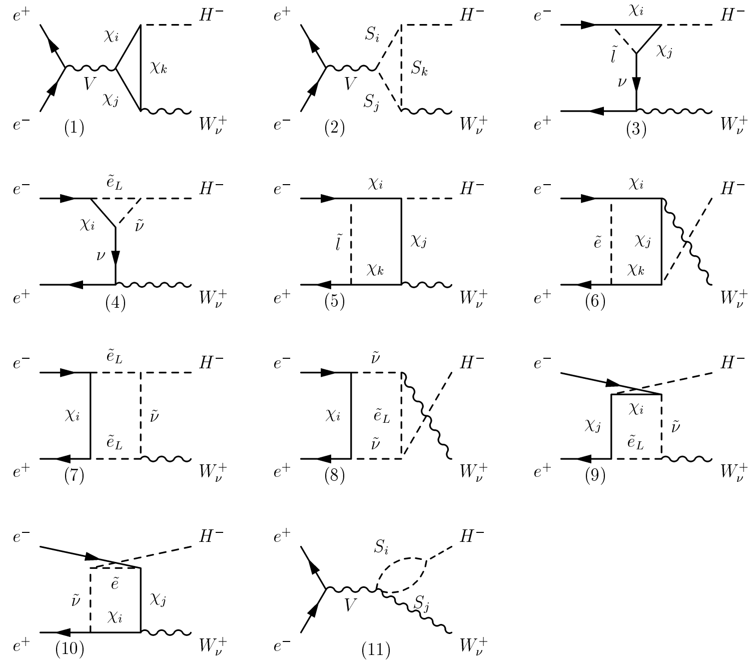


e^+ b H^- V t b e^- (1) W_ν^+
e^+ t H^- V b t e^- (2) W_ν^+
e^+ W H^- V S W e^- (3) W_ν^+
e^+ S_i H^- V W S_j e^- (4) W_ν^+
e^+ S_i H^- V S_k S_j e^- (5) W_ν^+
e^+ S_i H^- V S_j V' e^- (6) W_ν^+
e^+ V' H^- V S_j S_i e^- (7) W_ν^+
e^+ S H^- V W Z e^- (8) W_ν^+
e^+ H^- V S W e^- (9) W_ν^+
e^+ S_i H^- V S_j e^- (10) W_ν^+
e^+ Z H^- V S e^- (11) W_ν^+
e^+ W W_ν^+ ν S W e^- (12) H^-

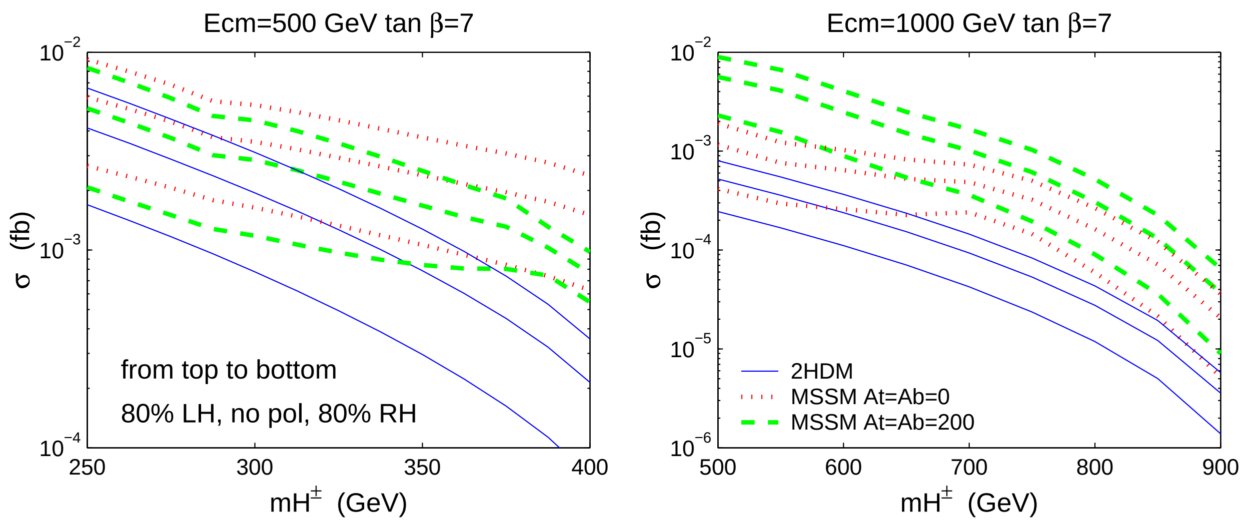


e^+ H^- V X e^- (1) W_ν^+
e^- H^- W ν e^+ (2) W_ν^+
e^+ H^- W^- V e^- (3) W_ν^+
e^+ H^- G^- V e^- (4) W_ν^+

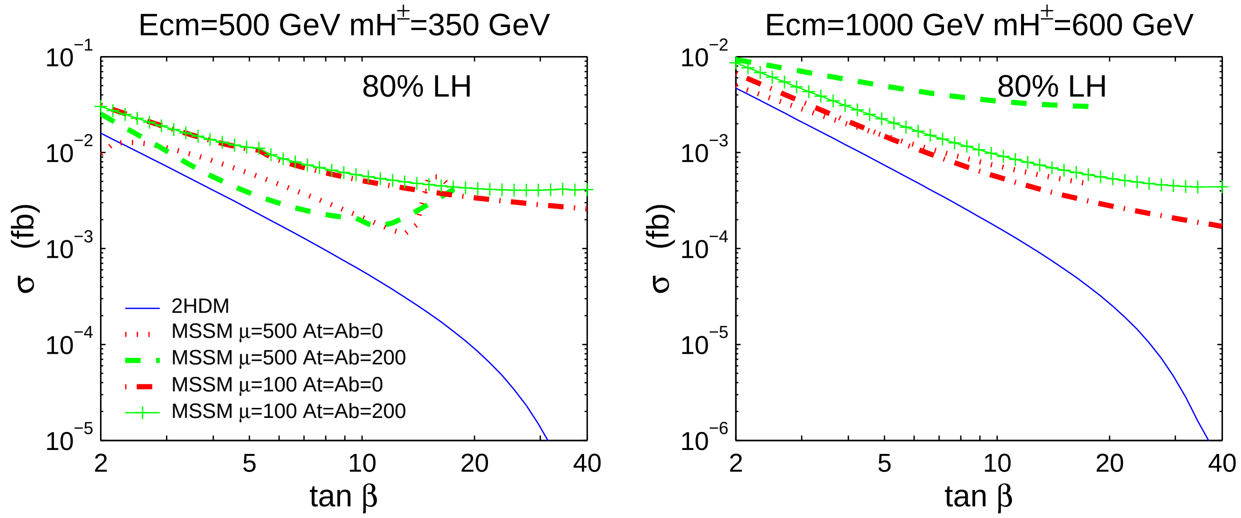
MSSM:

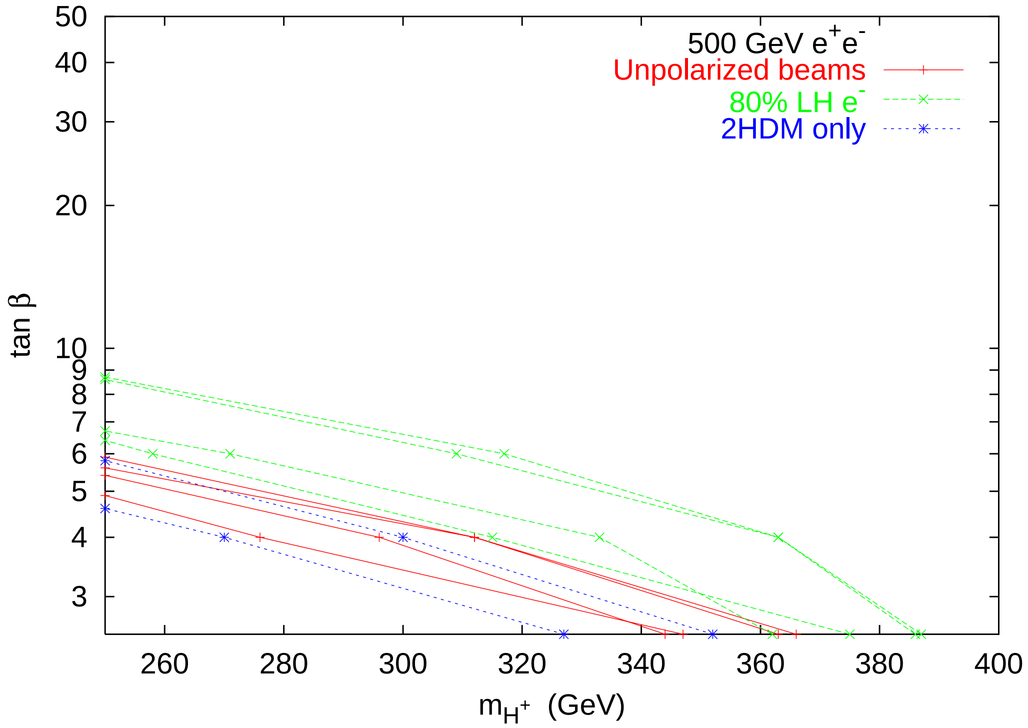


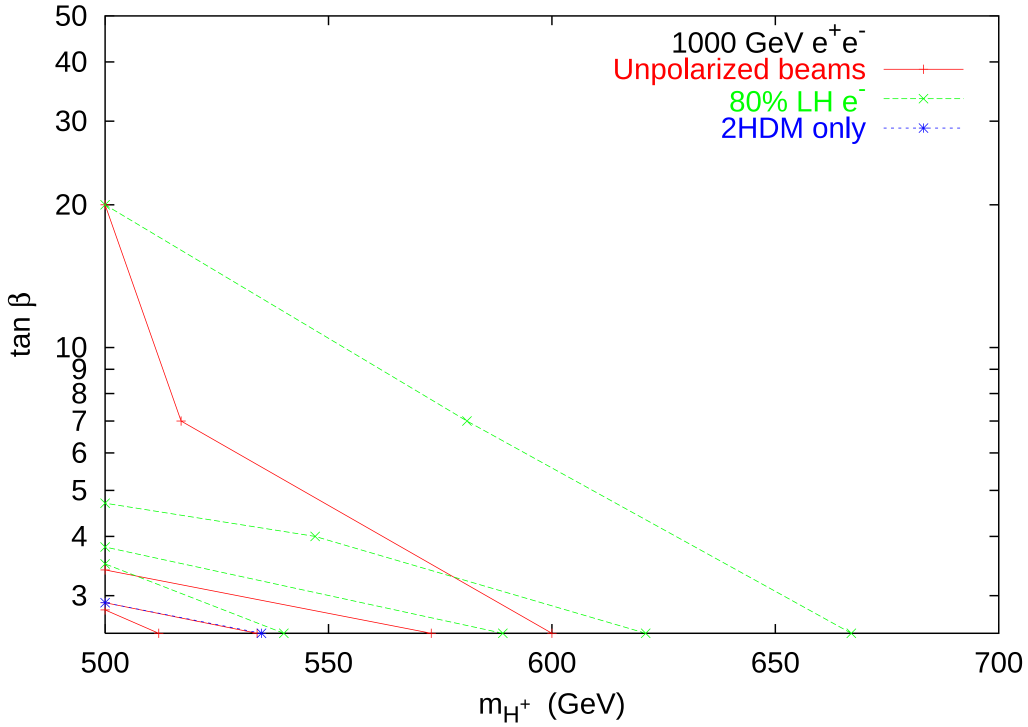
e^+ χ_i H^- V χ_k χ_j e^- (1) W_ν^+
e^+ S_i H^- V S_k S_j e^- (2) W_ν^+
e^- χ_i H^- $\tilde{l}$ χ_j ν e^+ (3) W_ν^+
e^- $\tilde{e}_L$ H^- χ_i $\tilde{\nu}$ ν e^+ (4) W_ν^+
e^- χ_i H^- $\tilde{l}$ χ_j χ_k e^+ (5) W_ν^+
e^- χ_i H^- $\tilde{e}$ χ_j χ_k e^+ (6) W_ν^+
e^- $\tilde{e}_L$ H^- χ_i $\tilde{\nu}$ $\tilde{e}_L$ e^+ (7) W_ν^+
e^- $\tilde{\nu}$ H^- χ_i $\tilde{e}_L$ $\tilde{\nu}$ e^+ (8) W_ν^+
e^- H^- χ_j χ_i $\tilde{\nu}$ $\tilde{e}_L$ e^+ (9) W_ν^+
e^- H^- $\tilde{e}$ $\tilde{\nu}$ χ_j χ_i e^+ (10) W_ν^+
e^+ S_i H^- V S_j e^- (11) W_ν^+



SUSY contributions also reduce the falloff of the cross section with increasing $\tan\beta$, thereby improving the $\tan\beta$ reach:







The various MSSM curves are for $M_{SUSY} = 200$ GeV, $\mu = 100$, 500 GeV and $A_t = A_b = 0$, 200 GeV.

Currently investigating constraint from h^0 mass bound – constrains stop mass and mixing parameter. Making the stops heavy decouples the stop-sbottom loops but does not have a big effect on the numerical results.

Competing processes for single production of $H^\pm$:

- $e^+e^- \to \tau^-\bar{\nu}H^+$, $\bar{t}bH^+$ – some reach at large $\tan\beta$: complementary to $e^+e^- \to W^+H^-$.

- $e^+e^- \to \bar{\nu}e^-H^+$ – calculation in progress. May be promising at large $\sqrt{s}$ because it is a t-channel process

- $e^-\gamma \to \nu H^-$ – too small in 2HDM; may be enhanced in MSSM?

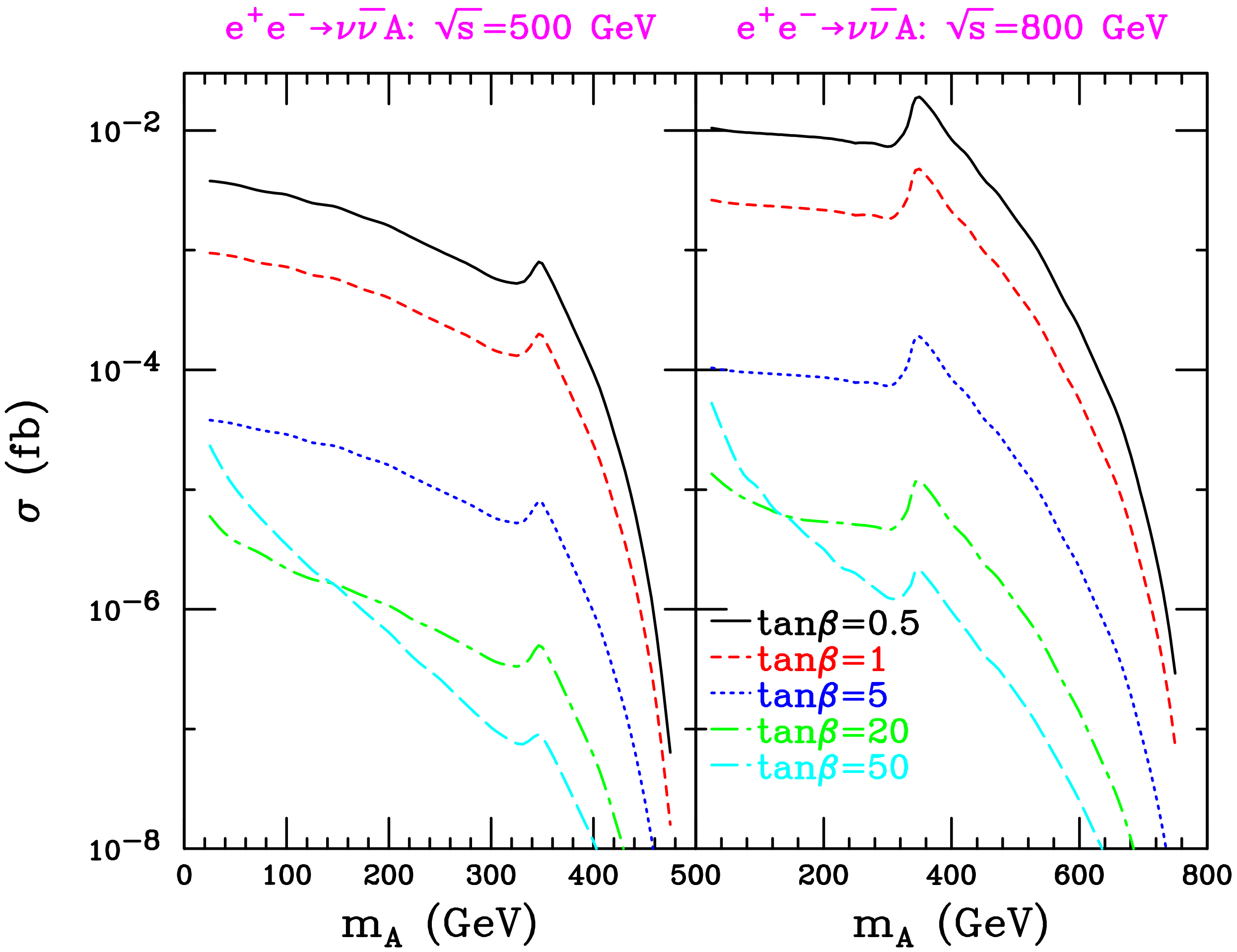
- $\gamma\gamma \to \tau^-\bar{\nu}H^+$ – quite good at large $\tan\beta$

- $\gamma\gamma \to W^+H^-$ – competitive with $e^+e^- \to W^+H^-$ at $\sqrt{s} = 1000$ GeV if 1000 fb^{-1} of e^+e^- luminosity is devoted to $\gamma\gamma$ collisions.

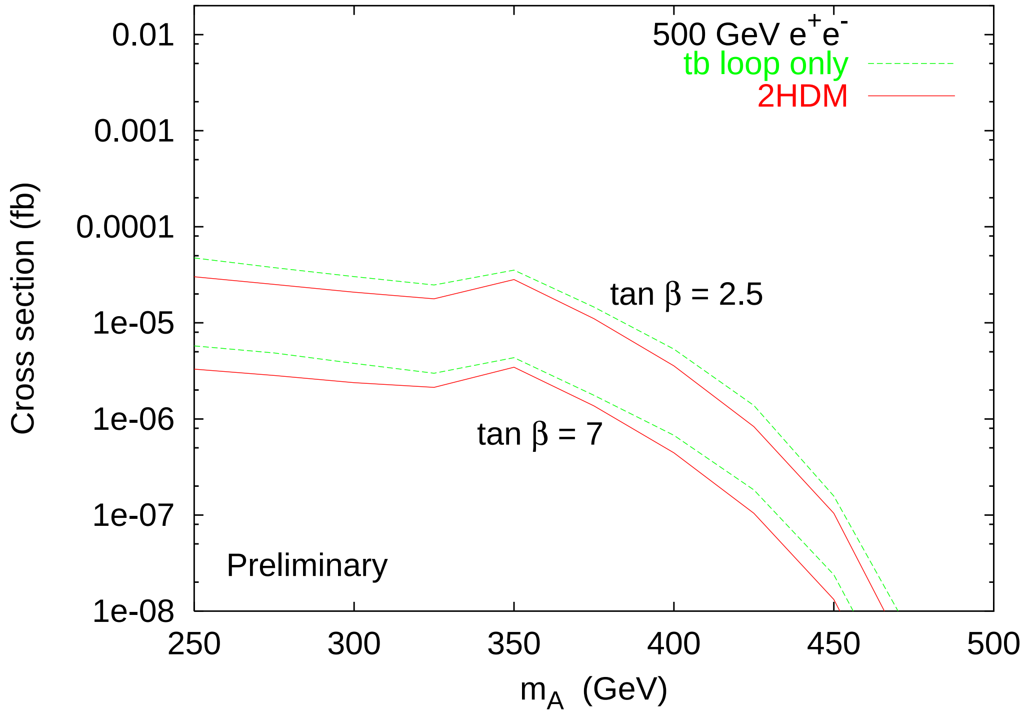
$$e^+e^- \to \nu\bar{\nu}A^0$$

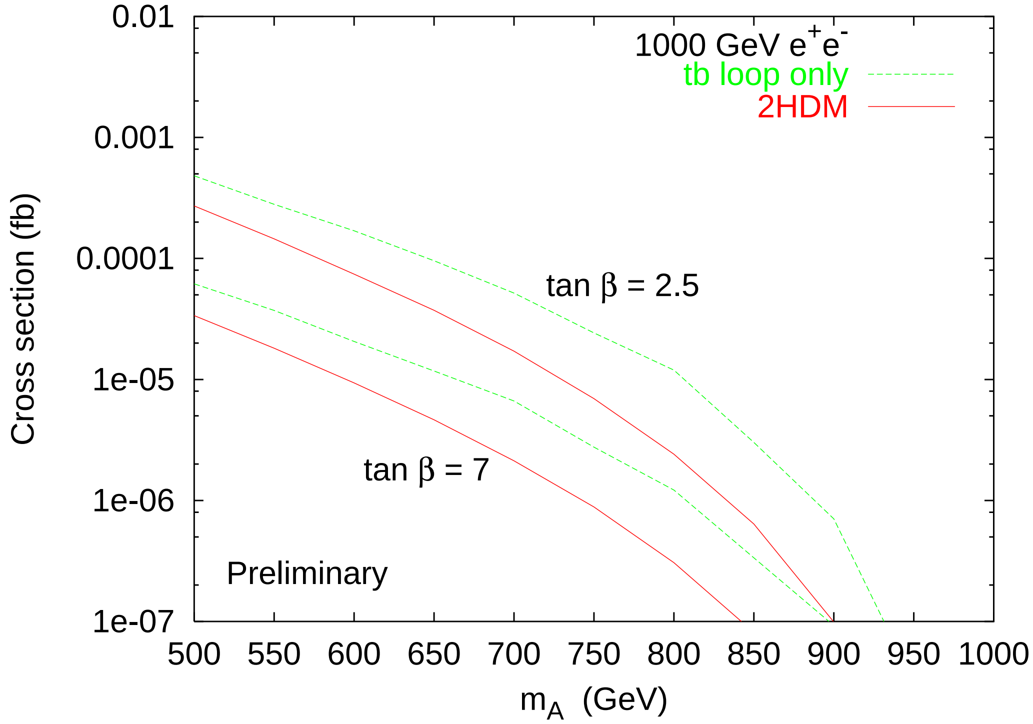
Calculations are in progress for this process in the 2HDM and full MSSM.

Preliminary results (tb triangle only) are in T. Farris, J. Gunion & H.L., hep-ph/0202087:



Cross sections in 2HDM are too small to be promising:





Summary and outlook

Higgs bosons heavier than $\sqrt{s}/2$ have to be singly produced in association with lighter particles.

The most promising channels in e^+e^- collisions are:

- 500 GeV: $b\bar{b}H^0$, ZH^0, h^0A^0, W^+H^-
- 1000 GeV: $\nu\bar{\nu}H^0$, W^+H^-

We calculated the SUSY contributions to $e^+e^- \to W^+H^-$.
$\to$ particularly promising for low $\tan\beta$ if the SUSY particles are light.

We also calculated $e^+e^- \to \nu\bar{\nu}A^0$ in the 2HDM. Unfortunately the cross sections are too small to be interesting.
Calculation of the SUSY contributions is in progress.

Other calculations in progress:

- 2HDM and MSSM contributions to $e^+e^- \to \bar{\nu}e^-H^+$. A vector boson fusion process – may be promising at large $\sqrt{s}$.
- MSSM contributions to $e^-\gamma \to \nu H^-$.