Single heavy MSSM Higgs production at a Linear Collider

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

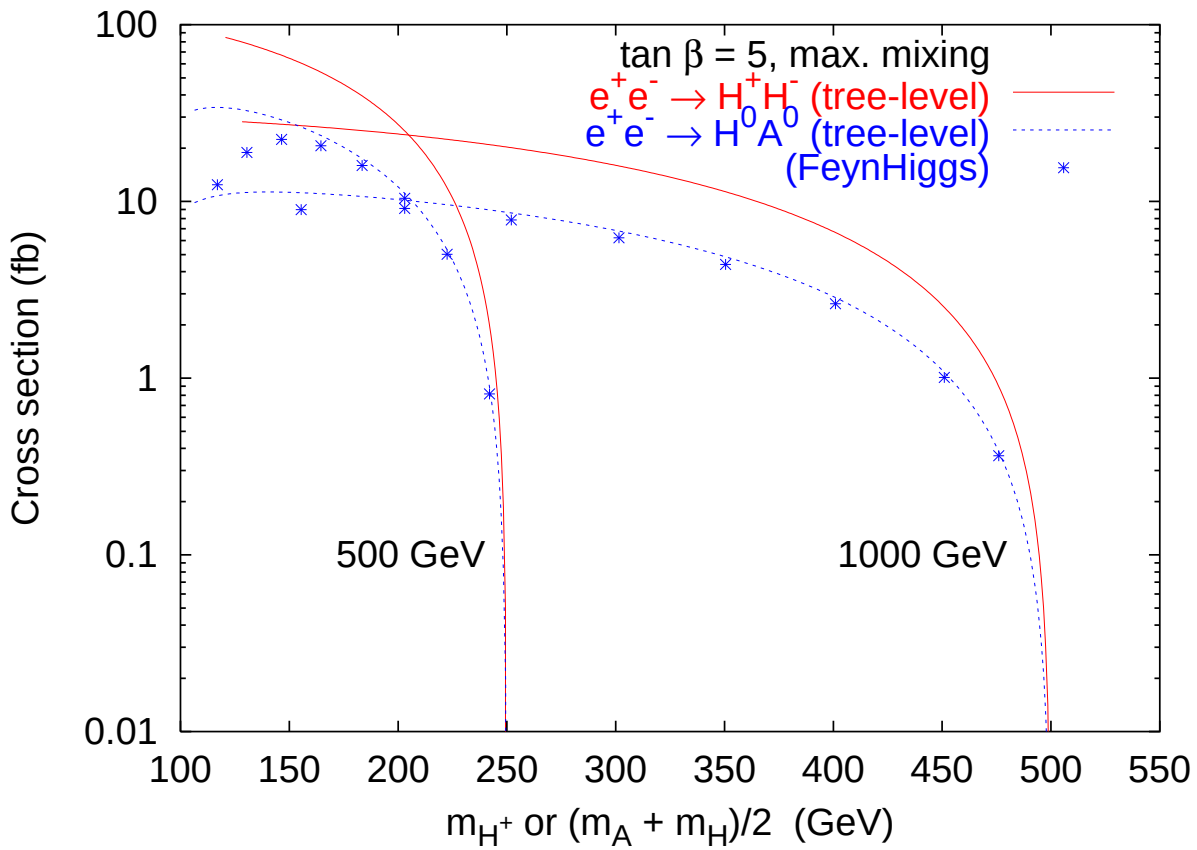
Measurements of the properties of the heavy Higgs bosons H^0, A^0 and $H^\pm$ of the MSSM can tell us a lot about the MSSM parameters.

- Heavy Higgs masses:
  - The heavy Higgs mass scale m_A (or equivalently, $m_{H^\pm}$) is an important MSSM parameter.
  - The MSSM predicts distinctive mass relations between m_A, m_H and $m_{H^\pm}$.
- Heavy Higgs couplings (probed in production and decays):
  - Couplings to fermions are sensitive to $\tan\beta$ and to potentially large SUSY radiative corrections to Yukawa couplings (Δ_b).
  - Couplings to sfermions (if kinematically accessible) may be sensitive to A-terms.
- Non-decoupling:
  - Even with high precision of LC measurements, 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, EPJC 19, 535 (2001) (www.feynhiggs.de)]
- $e^+e^- \to \nu\bar{\nu}H^0$
- $e^+e^- \to b\bar{b}H^0$, $b\bar{b}A^0$ [Gutierrez-Rodriguez et al, hep-ph/0110289; Cotti et al, PRD 59, 095011 (1999); QCD: Dittmaier et al, Dawson et al]
- $e^+e^- \to \tau^-\bar{\nu}H^+$, $\bar{t}bH^+$ [Kanemura et al, JHEP 0102, 011 (2001); Gutierrez-Rodriguez et al, hep-ph/0110289]
- $e^+e^- \to ZA^0$, γA^0 [Akeroyd et al, MPLA 14, 2093 (1999); PRD 64, 075007 (2001); Djouadi et al, NPB 491, 68 (1997)]
- $e^+e^- \to W^+H^-$ [Arhrib et al, NPB 581, 34 (2000); Kanemura, EPJC 17, 473 (2000); Zhu, hep-ph/9901221; Logan & Su, hep-ph/0203270]
- $e^+e^- \to \nu\bar{\nu}A^0$ [Farris et al, hep-ph/0202087]

$e^-\gamma$ collisions:

- $e^-\gamma \to \nu H^-$ [Kanemura et al, hep-ph/0104179]

$\gamma\gamma$ collisions:

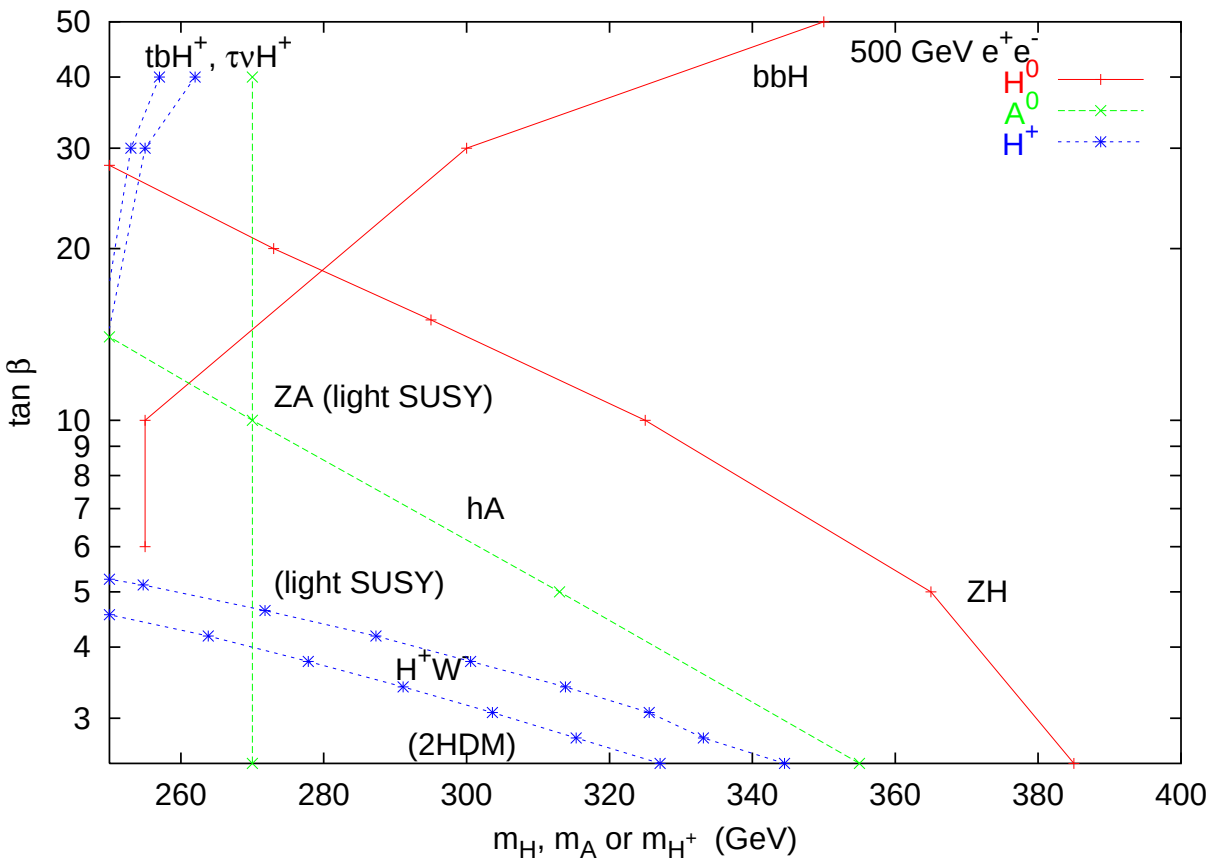
- $\gamma\gamma \to \tau^-\bar{\nu}H^+$ [He et al, hep-ph/0203090]
- $\gamma\gamma \to H^0$, A^0 [Gunion & Haber, PRD 48, 5109 (1993); Mühlleitner et al, PLB 508, 311 (2001); Asner et al, hep-ph/0110320]
- $\gamma\gamma \to W^+H^-$ [Zhou et al, PRD 64, 055005 (2001)]

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

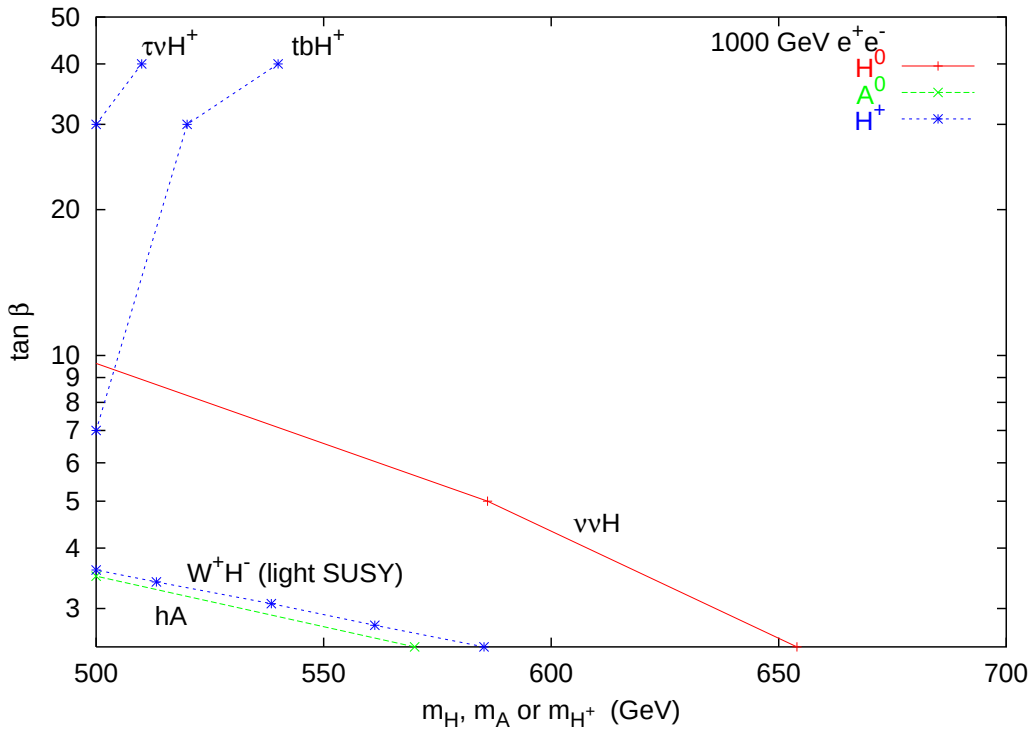
To compare the various modes, we look at areas where 10 or more signal events would be produced in the LC data sample.

- 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, $\nu\bar{\nu}A^0$

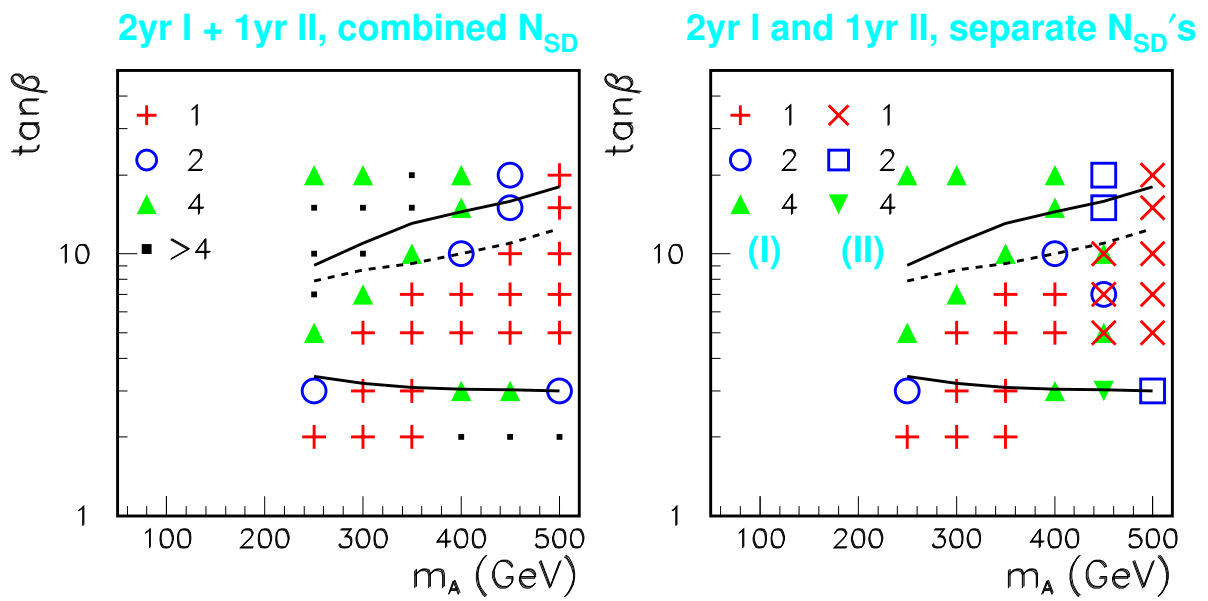


Too small to see: ZH^0, $b\bar{b}H^0$, $b\bar{b}A^0$, ZA^0, γA^0, $\nu\bar{\nu}A^0$

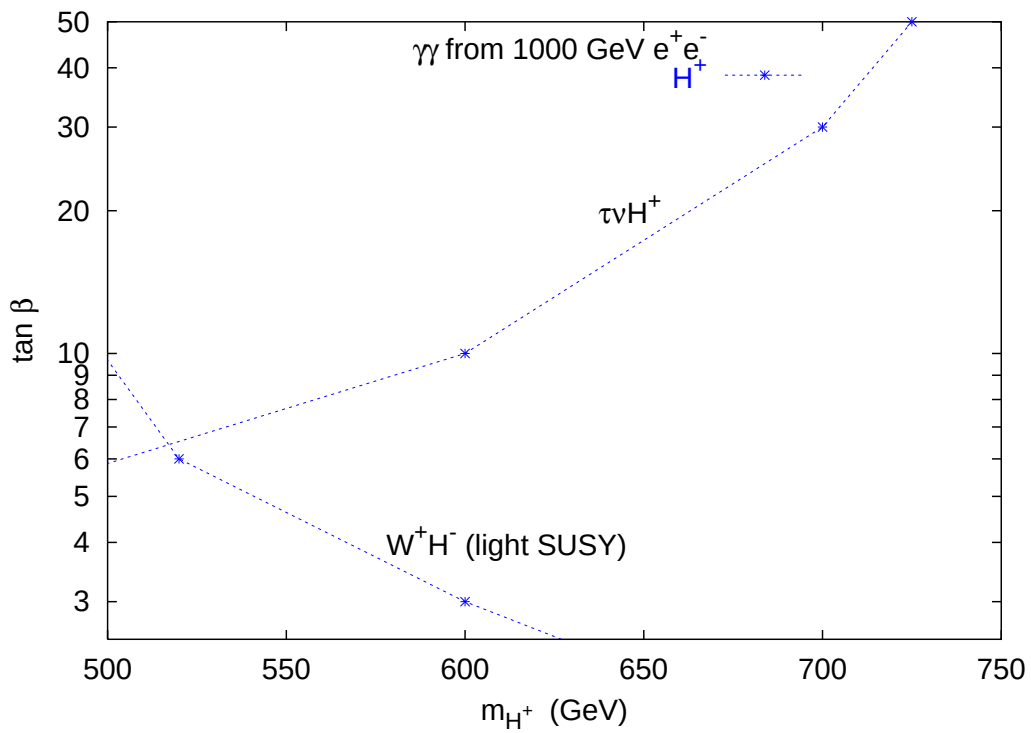
$e^-\gamma \to \nu H^-$ in the 2HDM is too small to be seen in the expected $e^-\gamma$ luminosity ($\sim$ 100 fb^{-1}).

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

Luminosity Factor Required for 4σ Discovery



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



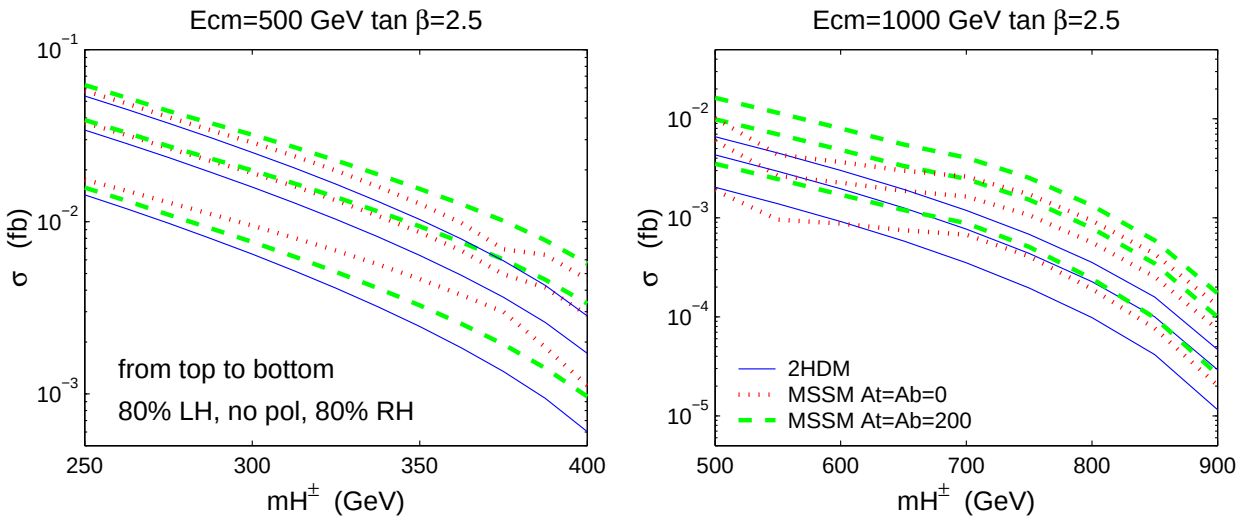
$e^+e^- \to W^+H^-$

$e^+e^- \to W^+H^-$ happens first at 1-loop, unless the Higgs sector is exotic (containing SU(2) triplets or larger representations).

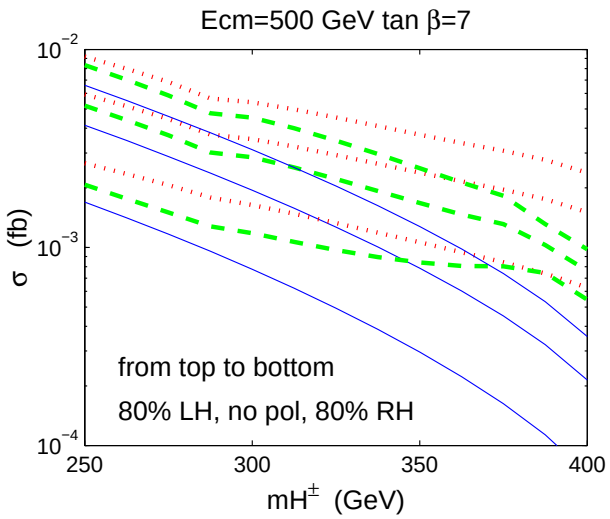
- Computed in the (non-supersymmetric) two Higgs doublet model in A. Arhrib *et al.*, NPB 581, 34 (2000) [also Kanemura; Zhu]

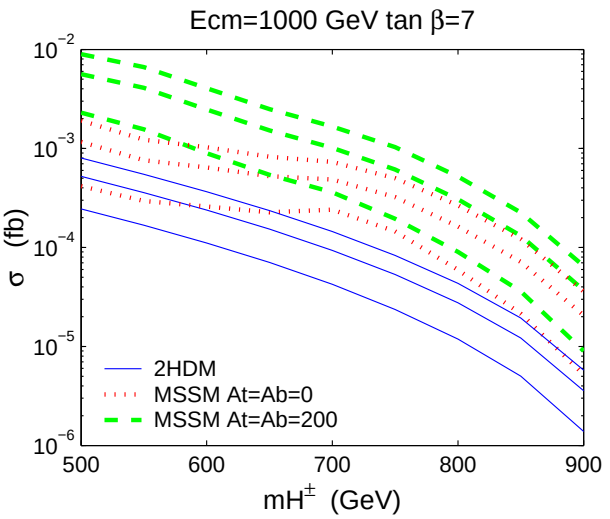
- Full MSSM calculation done in H.L. & S. Su, hep-ph/0203270

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

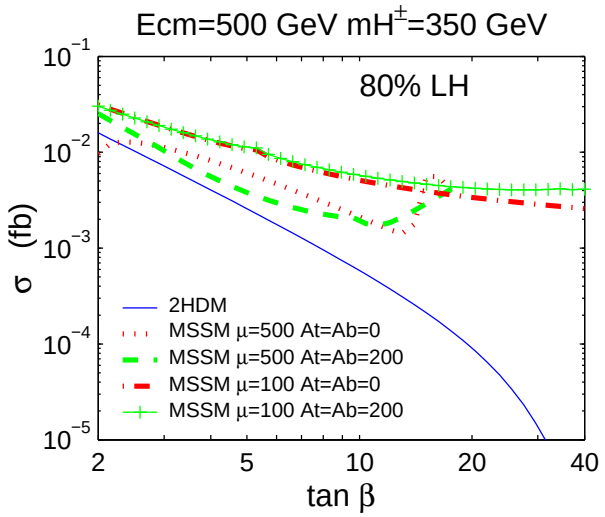


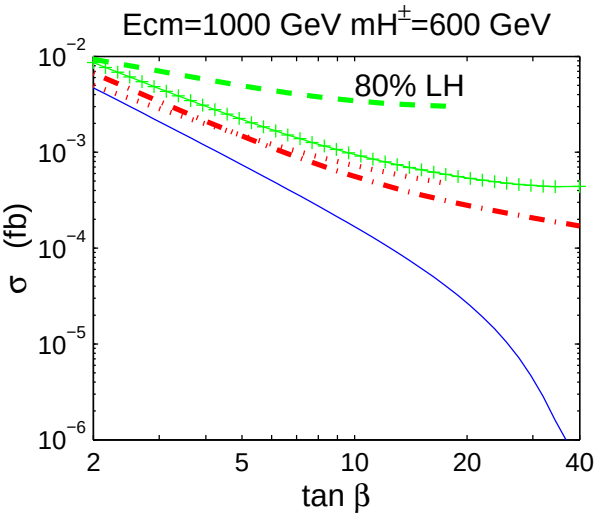
Left-polarized e^- beams also increase the cross section. Plots show 80% LH, unpolarized, and 80% RH e^- beams. The e^+ beams are assumed to be unpolarized.

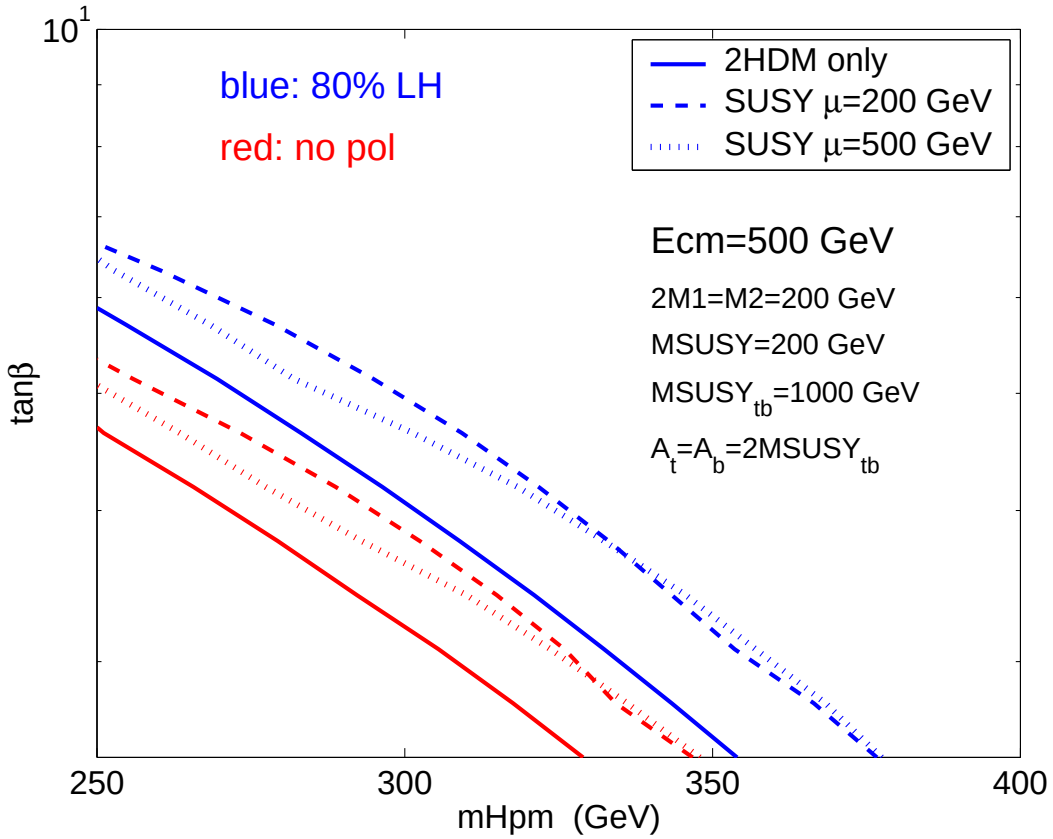


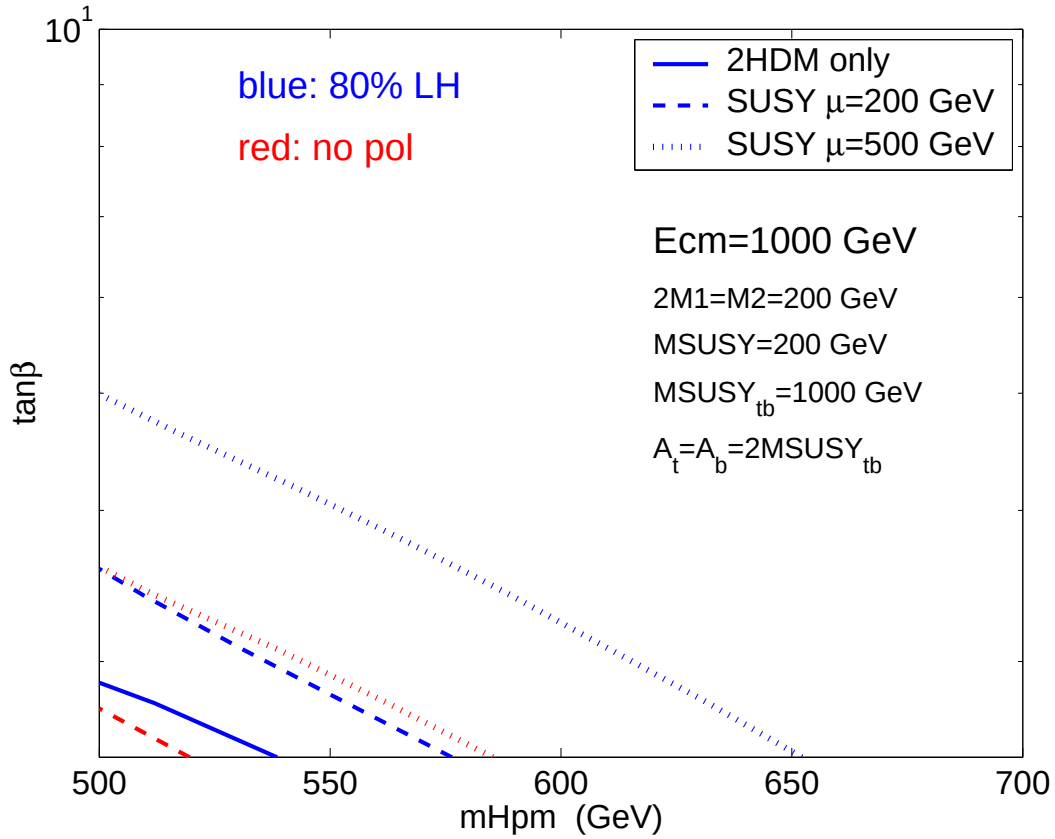


SUSY contributions also reduce the falloff of the cross section with increasing $\tan\beta$, thereby improving the $\tan\beta$ reach:






blue: 80% LH
red: no pol
2HDM only
SUSY μ=200 GeV
SUSY μ=500 GeV
Ecm=500 GeV
2M1=M2=200 GeV
MSUSY=200 GeV
MSUSY_tb=1000 GeV
A_t=A_b=2MSUSY_tb
tanβ
mHpm (GeV)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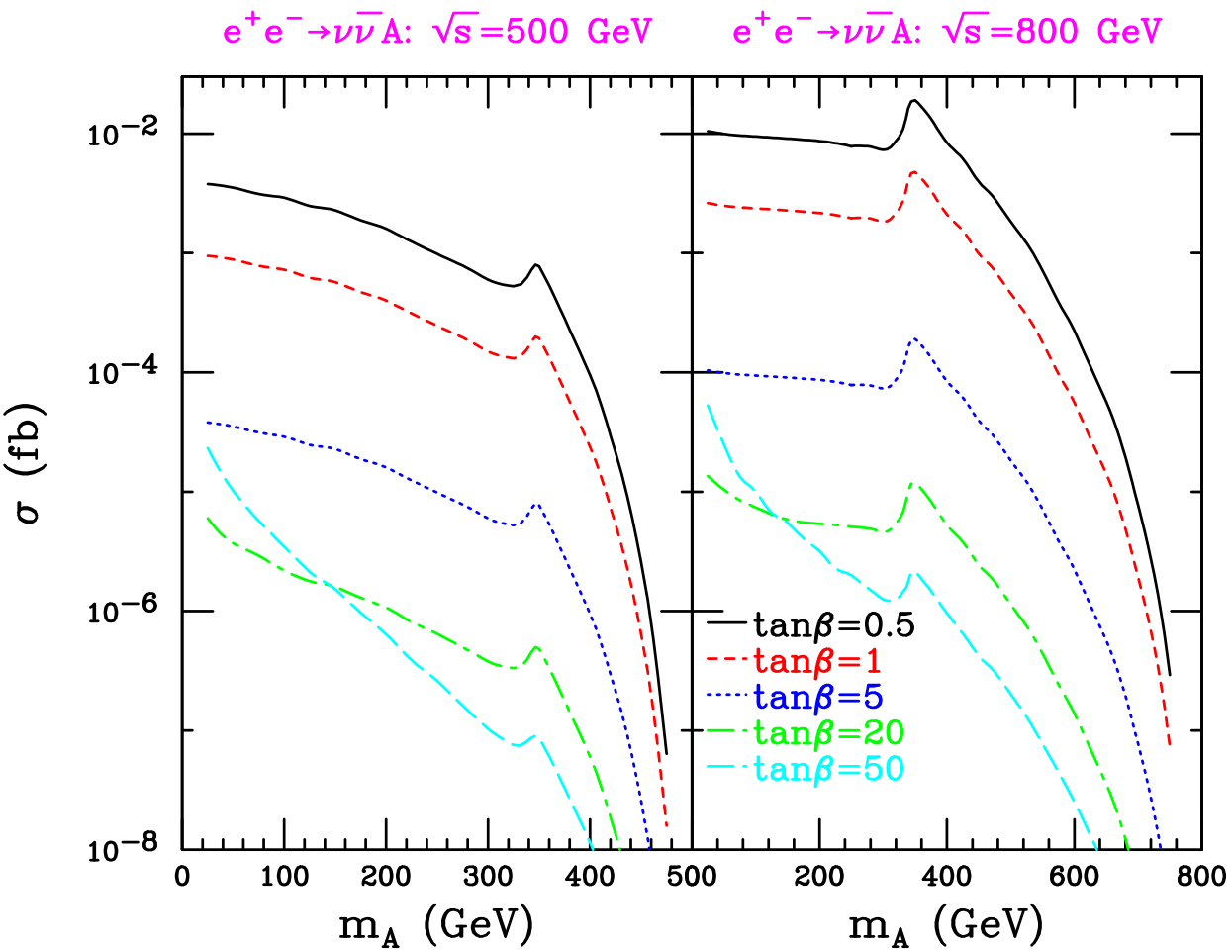
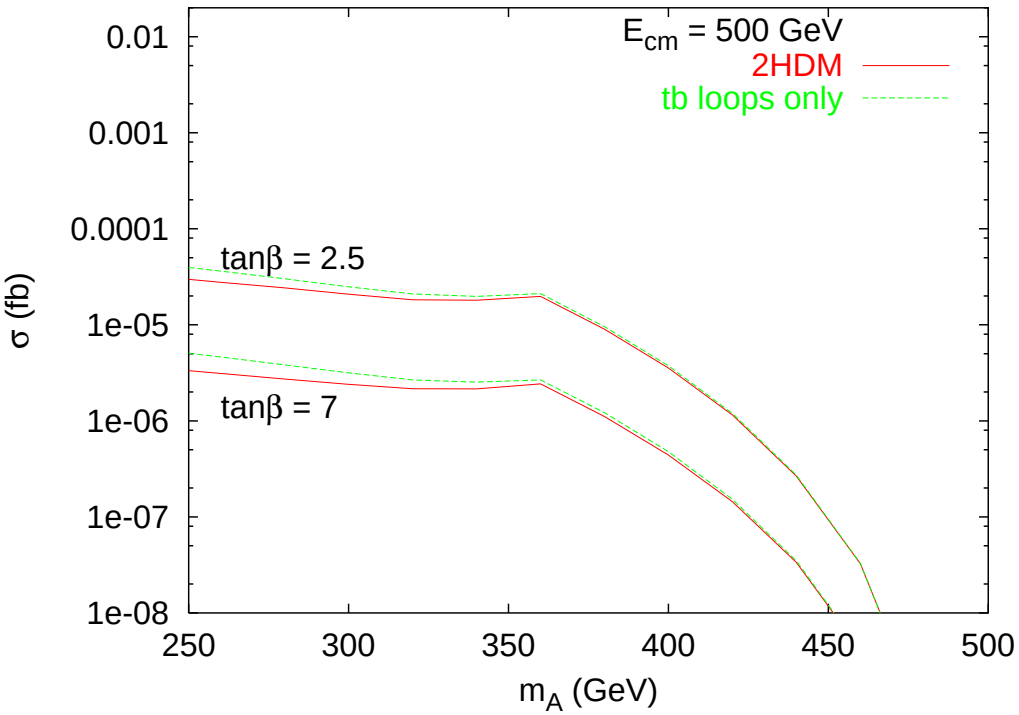
$e^+e^- \to \nu\bar{\nu}A^0$

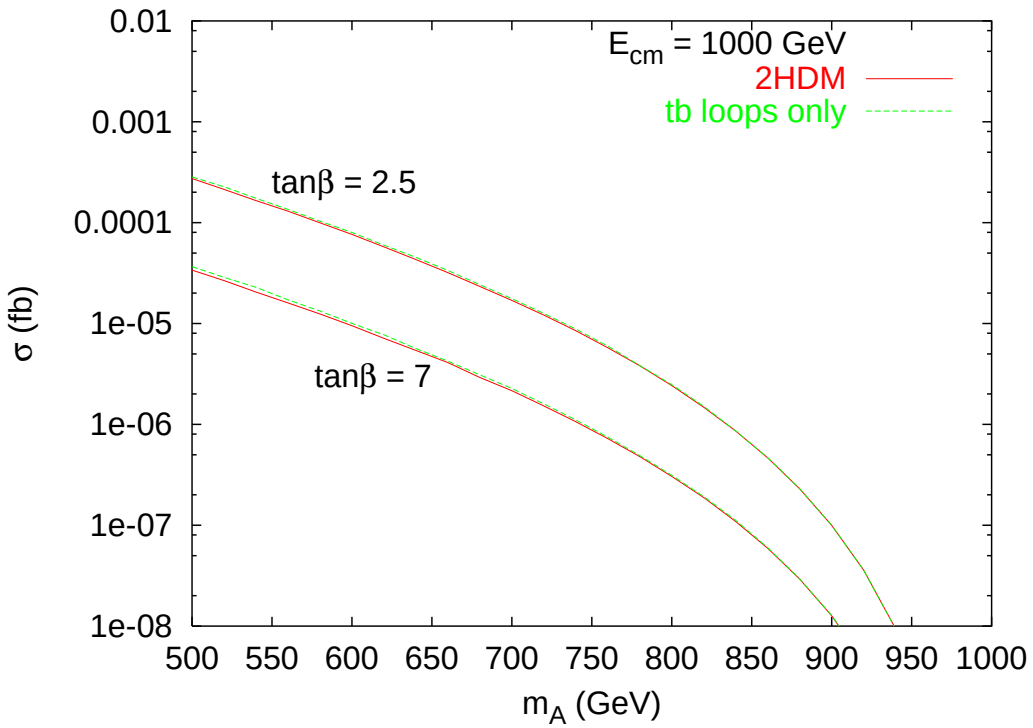
Preliminary results (tb triangle only) are in T. Farris, J. Gunion & H.L., hep-ph/0202087:



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

Cross sections in the MSSM-constrained 2HDM are too small to be promising:





Preliminary

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^-, $\bar{t}bH^+$

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, with MSSM constraints on the Higgs sector, the cross sections are too small to be interesting.
We're currently investigating the general 2HDM without MSSM constraints.

Loop calculations in progress:

- SUSY contributions to $e^+e^- \to \nu\bar{\nu}A^0$.
- 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 $e^-\gamma \to \nu H^-$.