Supersymmetric extensions of the Standard Model

(Lecture 2 of 4)

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Outline

Lecture 1: Introducing SUSY

Lecture 2: SUSY Higgs sectors

Lecture 3: Superpartner spectra and detection

Lecture 4: Measuring couplings, spins, and masses
In the last lecture we saw the two key features of the MSSM that impact Higgs physics:

- There are two Higgs doublets.

- The scalar potential is constrained by the form of the supersymmetric Lagrangian.

Let’s start with a closer look at each of these.
The MSSM requires two Higgs doublets
Reason #1: generating quark masses

The SM Higgs doublet is \( \Phi = \begin{pmatrix} \phi^+ \\ \phi_0 \end{pmatrix} \), with \( \langle \phi^0 \rangle = \frac{v}{\sqrt{2}} \).

Generate the down-type quark masses:

\[ \mathcal{L}_{\text{Yuk}} = -y_d \bar{d}_R \Phi^\dagger Q_L + \text{h.c.} \]
\[ = -y_d \bar{d}_R \left( \phi^-, \phi^{0*} \right) \begin{pmatrix} u_L \\ d_L \end{pmatrix} + \text{h.c.} \]
\[ = -y_d \frac{v}{\sqrt{2}} \left( \bar{d}_R d_L + \bar{d}_L d_R \right) + \text{interactions} \]
\[ = -m_d \bar{d}d + \text{interactions} \]

Generate the up-type quark masses:

\[ \mathcal{L}_{\text{Yuk}} = -y_u \bar{u}_R \Phi^\dagger Q_L + \text{h.c.?} \]

Does not work! Need to put the vev in the upper component of the Higgs doublet.

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Can sort this out by using the **conjugate doublet** $\tilde{\Phi}$:

\[
\tilde{\Phi} \equiv i\sigma_2\Phi^* = i \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \begin{pmatrix} \phi^- \\ \phi^{0*} \end{pmatrix} = \begin{pmatrix} \phi^{0*} \\ -\phi^- \end{pmatrix}
\]

\[
\mathcal{L}_{\text{Yuk}} = -y_u \bar{u}_R \tilde{\Phi}^\dagger Q_L + \text{h.c.}
\]

\[
= -y_u \bar{u}_R \begin{pmatrix} \phi^0, -\phi^+ \end{pmatrix} \begin{pmatrix} u_L \\ d_L \end{pmatrix} + \text{h.c.}
\]

\[
= -y_u \frac{v}{\sqrt{2}} (\bar{u}_R u_L + \bar{u}_L u_R) + \text{interactions}
\]

\[
= -m_u \bar{u}u + \text{interactions}
\]

Works fine in the SM!

But in SUSY we can’t do this, because $\mathcal{L}_{\text{Yuk}}$ comes from

\[
-\frac{1}{2} W^{ij} \psi_i \psi_j + \text{c.c. with } W^{ij} = M^{ij} + y^{ijk} \phi_k.
\]

$W$ must be analytic in $\phi$

$\longrightarrow$ not allowed to use complex conjugates.
Instead, need a second Higgs doublet with opposite hypercharge:

\[ H_1 = \left( \begin{array}{c} H_1^0 \\ H_1^- \end{array} \right) \quad H_2 = \left( \begin{array}{c} H_2^+ \\ H_2^0 \end{array} \right) \]

\[ \mathcal{L}_{\text{Yuk}} = -y_d \bar{d}_R \epsilon_{ij} H_1^i Q_L^j - y_u \bar{u}_R \epsilon_{ij} H_2^i Q_L^j + \text{h.c.} \quad \text{ok!} \]

\[ = -y_d \frac{v_1}{\sqrt{2}} \bar{d} d - y_u \frac{v_2}{\sqrt{2}} \bar{u} u + \text{interactions} \]

[lepton masses work just like down-type quarks]

Two important features:

- Both doublets contribute to the $W$ mass, so need $v_1^2 + v_2^2 = v_{SM}^2$. Ratio of vevs is not constrained; define parameter $\tan \beta = v_2 / v_1$.

- $\tan \beta$ shows up in couplings when $y_i$ are re-expressed in terms of fermion masses.

\[ y_d = \frac{\sqrt{2} m_d}{v \cos \beta} \quad y_u = \frac{\sqrt{2} m_u}{v \sin \beta} \quad y_\ell = \frac{\sqrt{2} m_\ell}{v \cos \beta} \]
The MSSM requires two Higgs doublets
Reason #2: anomaly cancellation

Chiral fermions (where the left-handed and right-handed fermions have different couplings) can cause chiral anomalies.

Anomaly diagram →

Breaks the gauge symmetry—generally very bad.

**Standard Model**: chiral anomalies all miraculously cancel within one fermion generation:

- Pure hypercharge:
  \[ \sum_{all \, f} Y_f^3 = 0 \]

- Hypercharge and QCD:
  \[ \sum_{all \, q} Y_q = 0 \]

- Hypercharge and SU(2):
  \[ \sum_{weak \, doublets} Y_d = 0 \]

Higgs has no effect on this since it’s not a chiral fermion.

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Supersymmetric models: Higgs is now part of a chiral supermultiplet. Paired up with chiral fermions! (Higgsinos)

The Higgsinos contribute to the chiral anomalies.

One Higgs doublet: carries hypercharge and SU(2) quantum numbers; gives nonzero $Y_f^3$ and $Y_d$ anomalies.

To solve this, introduce a second Higgs doublet with opposite hypercharge: sum of anomalies cancels.

[This is exactly the same as the requirement from generating up and down quark masses.]

MSSM is the minimal supersymmetric extension of the SM.
- Minimal SUSY Higgs sector is 2 doublets.
- More complicated extensions can have larger Higgs content (but must contain an even number of doublets).

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Higgs content of the MSSM

Standard Model: \[ \Phi = \left( \frac{\phi^+ + (v + \phi^0, r + i\phi^0, i) / \sqrt{2}}{\sqrt{2}} \right) \]

- Goldstone bosons \( G^+ = \phi^+ \), \( G^0 = \phi^0, i \) “eaten” by \( W^+ \) and \( Z \).
- One physical Higgs state \( H^0 = \phi^0, r \).

MSSM:

\[ H_1 = \left( \frac{(v_1 + \phi^0_1, r + i\phi^0_1, i) / \sqrt{2}}{\phi^-_1} \right) \]

\[ H_2 = \left( \frac{(v_2 + \phi^0_2, r + i\phi^0_2, i) / \sqrt{2}}{\phi^+_2} \right) \]

\[ \tan \beta \equiv \frac{v_2}{v_1} \]

- Still have one charged and one neutral Goldstone boson:
  \[ G^+ = -\cos \beta \phi^-_1 + \sin \beta \phi^+_2 \]
  \[ G^0 = -\cos \beta \phi^0_1, i + \sin \beta \phi^0_2, i \]
- Orthogonal combinations are physical particles: [mixing angle \( \beta \)]
  \[ H^+ = \sin \beta \phi^-_1 + \cos \beta \phi^+_2 \]
  \[ A^0 = \sin \beta \phi^0_1, i + \cos \beta \phi^0_2, i \]
- Two CP-even neutral physical states mix: [mixing angle \( \alpha \)]
  \[ h^0 = -\sin \alpha \phi^0_1, r + \cos \alpha \phi^0_2, r \]
  \[ H^0 = \cos \alpha \phi^0_1, r + \sin \alpha \phi^0_2, r \]
What are these physical states?

Masses and mixing angles are determined by the Higgs potential.

For the most general two-Higgs-doublet model:

\[
\mathcal{V} = m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - [m_{12}^2 \Phi_1^\dagger \Phi_2 + \text{h.c.}]
\]

\[
+ \frac{1}{2} \lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2} \lambda_2 (\Phi_2^\dagger \Phi_2)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1)
\]

\[
+ \left\{ \frac{1}{2} \lambda_5 (\Phi_1^\dagger \Phi_2)^2 + \left[ \lambda_6 (\Phi_1^\dagger \Phi_1) + \lambda_7 (\Phi_2^\dagger \Phi_2) \right] \Phi_1^\dagger \Phi_2 + \text{h.c.} \right\}
\]

from Haber & Davidson, PRD72, 035004 (2005)

MSSM is much more constrained, because of supersymmetry.

Supersymmetric part:

\[
\mathcal{L} \supset -W_i^* W_i - \frac{1}{2} \sum_{a} g_a^2 (\phi^* T^a \phi)^2
\]

recall \( W_i = M^{ij} \phi_j + \frac{1}{2} y^{ijk} \phi_j \phi_k \)
The only relevant part of the superpotential is $W = \mu H_1 H_2$. The rest of the SUSY-obeying potential comes from the D (gauge) terms, $V \supset \frac{1}{2} \sum_a g_a^2 (\phi^* T^a \phi)^2$.

$$V_{\text{SUSY}} = |\mu|^2 H_1^\dagger H_1 + |\mu|^2 H_2^\dagger H_2$$
$$+ \frac{1}{8} g'^2 \left( H_2^\dagger H_2 - H_1^\dagger H_1 \right)^2$$
$$+ \frac{1}{8} g^2 \left( H_1^\dagger \sigma^a H_1 + H_2^\dagger \sigma^a H_2 \right)^2$$

Note only one unknown parameter, $|\mu|^2!$ (g, g' are measured.)

But there is also SUSY breaking, which contributes three new quadratic terms:

$$V_{\text{breaking}} = m_{H_1}^2 H_1^\dagger H_1 + m_{H_2}^2 H_2^\dagger H_2 + \left[ b \epsilon_{ij} H_2^i H_1^j + \text{h.c.} \right]$$

Three more unknown parameters, $m_{H_1}^2$, $m_{H_2}^2$, and $b$. 
Combining and multiplying everything out yields the MSSM Higgs potential, at tree level:

\[ V = (|\mu|^2 + m^2_{H_1}) (|H^0_1|^2 + |H^-|^2) + (|\mu|^2 + m^2_{H_2}) (|H^0_2|^2 + |H^+_2|^2) \]
\[ + \left[ b (H^+_2 H^-_1 - H^0_2 H^0_1) + \text{h.c.} \right] \]
\[ + \frac{1}{8} \left( g^2 + g'^2 \right) \left( |H^0_2|^2 + |H^+_2|^2 - |H^0_1|^2 - |H^-_1|^2 \right)^2 \]
\[ + \frac{1}{2} g^2 \left| H^+_2 H^0_1^* + H^0_2 H^-_1^* \right|^2 \]

Dimensionful terms: \((|\mu|^2 + m^2_{H_{1,2}}), b\) set the mass-squared scale.
- \(\mu\) terms come from F-terms: SUSY-preserving
- \(m^2_{H_{1,2}}\) and \(b\) terms come directly from soft SUSY breaking

Dimensionless terms: fixed by the gauge couplings \(g\) and \(g'\)
- D-term contributions: SUSY-preserving

Three relevant unknown parameter combinations:
\((|\mu|^2 + m^2_{H_1}), (|\mu|^2 + m^2_{H_2}),\) and \(b\).

[All this is tree-level: it will get modified by radiative corrections.]

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The scalar potential fixes the vacuum expectation values, mass eigenstates, and 3– and 4–Higgs couplings.

**Step 1:** Find the minimum of the potential using \( \frac{\partial V}{\partial H_i} = 0 \). This lets you solve for \( v_1 \) and \( v_2 \) in terms of the Higgs potential parameters. Usually use these relations to eliminate \( (|\mu|^2 + m_{H_1}^2) \) and \( (|\mu|^2 + m_{H_2}^2) \) in favor of the vevs.

[Eliminate one unknown: \( v_1^2 + v_2^2 = v_{SM}^2 \).]

**Step 2:** Plug in the vevs and collect terms quadratic in the fields. These are the mass terms (and generically include crossed terms like \( H_1^+ H_2^- \)). Write these as \( M_{ij}^2 \phi_i \phi_j \) and diagonalize the mass-squared matrices to find the mass eigenstates.
Results: Higgs masses and mixing angle

[Only 2 unknowns: $\tan \beta$ and $M_{A^0}$.]

\[
M^2_{A^0} = \frac{2b}{\sin 2\beta} \quad M^2_{H^\pm} = M^2_{A^0} + M^2_W
\]

\[
M^2_{h^0,H^0} = \frac{1}{2} \left( M^2_{A^0} + M^2_Z \mp \sqrt{(M^2_{A^0} + M^2_Z)^2 - 4M^2_Z M^2_{A^0} \cos^2 2\beta}\right)
\]

[By convention, $h^0$ is lighter than $H^0$]

Mixing angle for $h^0$ and $H^0$:

\[
\frac{\sin 2\alpha}{\sin 2\beta} = -\frac{M^2_{A^0} + M^2_Z}{M^2_{H^0} - M^2_{h^0}} \quad \frac{\cos 2\alpha}{\cos 2\beta} = -\frac{M^2_{A^0} - M^2_Z}{M^2_{H^0} - M^2_{h^0}}
\]

[Note $M^2_W = g^2 v^2 / 4$ and $M^2_Z = (g^2 + g'^2) v^2 / 4$: these come from the $g^2$ and $g'^2$ terms in the scalar potential.]

- $A^0$, $H^0$ and $H^\pm$ masses can be arbitrarily large: grow with $\frac{2b}{\sin 2\beta}$.
- $h^0$ mass is bounded from above: $M_{h^0} < |\cos 2\beta| M_Z \leq M_Z$ (!!) 

This is already ruled out by LEP! The MSSM would be dead if not for the large radiative corrections to $M_{h^0}$.

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Mass matrix for $\phi_{1,2}^{0,r}$:

\[ M^2 = \begin{pmatrix} M_A^2 \sin^2 \beta + M_Z^2 \cos^2 \beta & -(M_A^2 + M_Z^2) \sin \beta \cos \beta \\ -(M_A^2 + M_Z^2) \sin \beta \cos \beta & M_A^2 \cos^2 \beta + M_Z^2 \sin^2 \beta \end{pmatrix} \]

Radiative corrections come mostly from the top and stop loops.

New mass matrix:

\[ M^2 = M^2_{\text{tree}} + \begin{pmatrix} \Delta M^2_{11} & \Delta M^2_{12} \\ \Delta M^2_{21} & \Delta M^2_{22} \end{pmatrix} \]

Have to re-diagonalize.

Leading correction to $M_{h0}$:

\[ \Delta M^2_{h0} \approx \frac{3}{4\pi^2} v^2 y_t^4 \sin^4 \beta \ln \left( \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2} \right) \]

Revised bound (full 1-loop + dominant 2-loop): $M_{h0} \lesssim 135$ GeV.
Higgs masses as a function of $M_A$ [for $\tan \beta$ small (3) and large (30)]

For large $M_A$:  
- $M_h$ asymptotes  
- $M_{H0}$ and $M_{H+}$ become increasingly degenerate with $M_A$

from Carena & Haber, hep-ph/0208209
Higgs couplings

Higgs couplings to fermions are controlled by the Yukawa Lagrangian,

\[ \mathcal{L}_{\text{Yuk}} = -y_\ell \bar{e}_R \epsilon_{ij} H^i L^j_L - y_d \bar{d}_R \epsilon_{ij} H^i Q^j_L - y_u \bar{u}_R \epsilon_{ij} H^i Q^j_L + \text{h.c.} \]

tan \beta\text{-dependence shows up in couplings when } y_i \text{ are re-expressed in terms of fermion masses:}

\[ y_\ell = \frac{\sqrt{2} m_\ell}{v \cos \beta} \quad y_d = \frac{\sqrt{2} m_d}{v \cos \beta} \quad y_u = \frac{\sqrt{2} m_u}{v \sin \beta} \]

Higgs couplings to gauge bosons are controlled by the SU(2) structure.

Plugging in the mass eigenstates gives the actual couplings.

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Couplings of $h^0$ (the light Higgs)

\[ h^0 W^+ W^- : i g M_W g_{\mu \nu} \sin(\beta - \alpha) \]
\[ h^0 ZZ : i \frac{g M_Z}{\cos \theta_W} g_{\mu \nu} \sin(\beta - \alpha) \]
\[ h^0 \bar{b} \bar{b} : i \frac{g m_b}{2 M_W} \left[ \sin(\beta - \alpha) - \tan \beta \cos(\beta - \alpha) \right] \]
\[ h^0 \ell^+ \ell^- : i \frac{g m_{\ell}}{2 M_W} \left[ \sin(\beta - \alpha) + \cot \beta \cos(\beta - \alpha) \right] \]

[h^0 \ell^+ \ell^- coupling has same form as $h^0 \bar{b} \bar{b}$]

Controlled by $\tan \beta$ and the mixing angle $\alpha$.

In the "decoupling limit" $M_{A^0} \gg M_Z$, $\cos(\beta - \alpha)$ goes to zero:

\[ \cos(\beta - \alpha) \simeq \frac{1}{2} \sin 4\beta \frac{M_Z^2}{M_{A^0}^2} \]

Then all the $h^0$ couplings approach their SM values!
LEP searches for $h^0$

$e^+e^- \rightarrow Z^* \rightarrow Zh^0$: coupling $\frac{igM_Z}{\cos\theta_W}g_{\mu\nu}\sin(\beta - \alpha)$

- Production can be suppressed compared to SM Higgs
LEP searches for $h^0$

$$e^+e^- \rightarrow Z^* \rightarrow h^0A^0: \text{coupling } \propto \cos(\beta - \alpha)$$

- Complementary to $Zh^0$
- Combine searches for overall MSSM exclusion

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LHC searches for $h^0$

Decoupling limit
(large $M_{A_0}$):

- $h^0$ search basically the same as SM Higgs search

- Mass $\lesssim 135$ GeV:
  lower-mass search channels most important

- Challenging channels

**Figure 16:**

Couplings of $H^0$ and $A^0$

\[ H^0 W^+ W^- : \quad ig_{M_W} g_{\mu\nu} \cos(\beta - \alpha) \]
\[ H^0 ZZ : \quad ig_{M_Z} \cos(\beta - \alpha) \]
\[ H^0 \bar{t}t : \quad ig_m \left[ -\cot \beta \sin(\beta - \alpha) + \cos(\beta - \alpha) \right] \]
\[ H^0 \bar{b}b : \quad ig_m \left[ \tan \beta \sin(\beta - \alpha) + \cos(\beta - \alpha) \right] \]
\[ A^0 \bar{t}t : \quad \frac{g_m}{2M_W} \cot \beta \gamma^5 \quad A^0 \bar{b}b : \quad \frac{g_m}{2M_W} \tan \beta \gamma^5 \]

Couplings to leptons have same form as $\bar{b}b$.

Remember the decoupling limit $\cos(\beta - \alpha) \to 0$:
- $\bar{b}b$ and $\tau\tau$ couplings go like $\tan \beta$: can be strongly enhanced.
- $\bar{t}t$ couplings go like $\cot \beta$: can be strongly suppressed.

Can’t enhance $\bar{t}t$ coupling much: perturbativity limit.
Tevatron searches for $H^0$ and $A^0$

Use $bbH^0$, $bbA^0$ couplings: enhanced at large $\tan\beta$
- $bb \rightarrow H^0, A^0$, decays to $\tau\tau$ (most sensitive) or $bb$

$\tau\tau$ channel, CDF + DZero, arXiv:1003.3363

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LHC searches for $H^0$ and $A^0$

Same idea, higher mass reach because of higher beam energy and luminosity

$bb \rightarrow H^0, A^0 \rightarrow \mu \mu$ channel: rare decay but great mass resolution!

$\mu \mu$ channel, ATLAS CSC book, arXiv:0901.0512
Couplings of $H^\pm$

$$H^+\tau^-\bar{\nu} : i\frac{g}{\sqrt{2}M_W}[m_\tau \tan \beta P_R]$$

Important for decays

$$H^+\bar{t}b : i\frac{g}{\sqrt{2}M_W}V_{tb}[m_t \cot \beta P_L + m_b \tan \beta P_R]$$

Important for production and decays

$H^+\bar{c}s$ coupling has same form

Couplings to another Higgs and a gauge boson are usual SU(2) form.

$\gamma H^+H^-, ZH^+H^-$  
Search for pair production at LEP

$W^+H^-A^0, W^+H^-H^0$  
Associated production at LHC
LEP searches for $H^\pm$

\[ e^+e^- \rightarrow \gamma^*, Z^* \rightarrow H^+H^- \]

$H^\pm$ decays to $\tau\nu$ or $cs$
- Assume no other decays

Major background from $W^+W^-$ especially for $H^+ \rightarrow cs$

Limit $M_{H^+} > 78.6$–$89.6$ GeV

LEP combined, hep-ex/0107031
Tevatron searches for $H^\pm$

Look for $t \to H^+ b$.
- Sensitive at high and low $\tan \beta$.
- Decays to $\tau \nu$ or $c s$.

$\text{BR}(H^+ \to c \bar{s}) = 1$:
Look for $M_{jj} \neq M_W$.

$\text{BR}(H^+ \to \tau \nu) > 0$:
Look at final-state fractions.

CDF, PRL103, 101803 (2009)

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LHC searches for $H^\pm$

Light charged Higgs:

- top decay $t \rightarrow H^+ b$ with $H^+ \rightarrow \tau\nu$.

Heavy charged Higgs:

- associated production $pp \rightarrow t H^-$. 
- most of sensitivity with $H^+ \rightarrow \tau\nu$; $H^+ \rightarrow t\bar{b}$ contributes but large background.

Search for all the MSSM Higgs bosons at LHC

ATLAS, 300 fb⁻¹, $m_h^{\text{max}}$ scenario. From Haller, hep-ex/0512042

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What if only $h^0$ is accessible?

Try to distinguish it from the SM Higgs using coupling measurements.

\[
\begin{align*}
    h^0 W^+ W^- : & \quad i g M_W g_{\mu\nu} \sin(\beta - \alpha) \\
    h^0 ZZ : & \quad i \frac{g M_Z}{\cos \theta_W} g_{\mu\nu} \sin(\beta - \alpha) \\
    h^0 \bar{t}t : & \quad i \frac{g m_t}{2 M_W} [\sin(\beta - \alpha) + \cot \beta \cos(\beta - \alpha)] \\
    h^0 \bar{b}b : & \quad i \frac{g m_b}{2 M_W} [\sin(\beta - \alpha) - \tan \beta \cos(\beta - \alpha)]
\end{align*}
\]

Other couplings:
- $ggh^0$: sensitive to $h^0 \bar{t}t$ coupling, top squarks in the loop.
- $h^0 \gamma\gamma$: sensitive to $h^0 W^+ W^-$, $h^0 \bar{t}t$, couplings, charginos and top squarks in the loop.
Coupling fit at the LHC:
Look for discrepancies from SM predictions

Major motivation for ILC: probe $h^0$ couplings with much higher precision.

Logan & Droll, PRD76, 015001 (2007)
Going beyond the MSSM

Simplest extension of MSSM is to add an extra Higgs particle.
- NMSSM, nMSSM, MNSSM, etc.

New chiral supermultiplet $S$
- Gives an “extra Higgs”
- Couples only to other Higgses (before mixing): hard to detect, can be quite light
- Exotic decays $h^0 \rightarrow ss$
- Decays $s \rightarrow \bar{b}b$, $\tau \tau$, $\gamma \gamma$ made possible by mixing

Lisanti & Wacker, PRD79, 115006 (2009)
New chiral supermultiplet $S$ also gives an extra neutralino $\tilde{s}$
- Makes the neutralino sector more complicated: may need LHC and ILC synergy to unravel.

Moortgat-Pick et al, hep-ph/0508313
New chiral supermultiplet $S$ also gives an extra neutralino $\tilde{s}$
- Dark matter particle, can be quite light
- Invisible Higgs decay $h^0 \to \tilde{s}\tilde{s}$ if light enough

Plot: ATLAS with 30 fb$^{-1}$. Scaling factor $\xi^2\sigma_{SM} \equiv \sigma \times \text{BR}(H \to \text{invis})$

**Comparison of the discovery potential for different channels**

$ZH_{\text{inv}}$ – uses $Z \to \ell^+\ell^-$

VBF looks very good, but not clear how well events can be triggered.

$t\bar{t}H_{\text{inv}}$ – may be room for improvement? ATLAS study in progress.
Summary

MSSM Higgs sector has a rich phenomenology

One Higgs boson $h^0$
- Can be very similar to SM Higgs
- Mass is limited by MSSM relations, $\lesssim 135$ GeV

Set of new Higgs bosons $H^0, A^0$, and $H^\pm$
- Can be light or heavy
- Search strategy depends on mass, $\tan \beta$

Beyond the MSSM:
- Usually one more new Higgs
- Can have dramatic effect on Higgs phenomenology