Supersymmetry without a light higgs boson at the LHC

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Higgs particle is missing and indirect information about its mass can be obtained under some prior using precision data and, assuming new physics doesn’t affect S and T, \( m_h \) can be bounded: \( 76^{+33}_{-24} \) GeV
SuSy effect can be quite mild in this analysis, leaving SM results almost untouched, but in this case the lightest CP-even scalar can’t be much heavier than $m_Z$.

**What if Nature is supersymmetric and the higgs is heavy?**


\[ W = \lambda S H_u \cdot H_d + W_{\text{MSSM}} \]

\( \lambda \) is not bound by unification* but only by calculability of EWPO \( \Rightarrow m_h \gg m_h^{\text{MSSM}} \)

- \( \lambda = 2 \Rightarrow m_h \simeq 250 \text{GeV} \)
- \( 1.5 \leq \tan \beta \leq 3 \Rightarrow \text{prod.} \sim \text{SM} \)
- \( 350 \text{GeV} \leq m_{H^+} \leq 700 \text{GeV} \)

no corrections from heavy \( \tilde{t} \Rightarrow \text{fully natural} \)

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* a unification compatible UV completion exists
The model

\[ W = \mu(S)H_1 \cdot H_2 + f(S) \]

\[ V = \sum_i \mu_i(S) |H_i|^2 - \mu_3^2(S)(H_1H_2 + h.c.) + \lambda^2 |H_1 \cdot H_2|^2 + V(S) + \text{small} \]

We assume the singlet is heavy \( \sim 1 \text{ TeV} \) and nearly not mixed with the other scalars (little correction in any case)

**Natural Spectrum**

- \( m_h > 2m_W \) is natural
- masses are function of only \( \lambda \), \( m_{H^\pm} \) and \( \tan \beta \)
- \( m_h < m_{H^\pm} < m_H < m_A \)
Phenomenology

\( \tilde{g} \) and \( \tilde{t} \)

Naturalness bounds (with 20% FT):

\[
\begin{align*}
    m_{\tilde{t}} & \lesssim 600 - 800 \text{GeV} \\
    m_{\tilde{g}} & \lesssim 1.2 - 1.6 \text{TeV}
\end{align*}
\]

while we can take all other \( \tilde{q} \), \( \tilde{l} \) and gaugino to be heavier.

Standard searches for decay chains with jets, leptons and \( E_T \) apply and these particle are detectable with \( 10 fb^{-1} \) or less.

**DM**

The lightest neutralino benefits of singlino-higgsino mixing and can be a DM with \( m_{\chi_0} \approx 100 - 200 \text{GeV} \)
light higgs

Properties

- $m_h \sim 200 - 300 \text{GeV}$
- $\Gamma_h \sim 2 - 8 \text{GeV}$
- $g_{HVV} \simeq g^{SM}_{HVV}$
- $g_{Htt} \simeq g^{SM}_{Htt}$

$h \rightarrow ZZ \rightarrow 4l$

- SM studies apply. Mass and width can be measured.
- Precision is not enough to discriminate between SM and $\lambda$SUSY higgs.

Puzzling Supersymmetry?

This higgs boson is at odds with MSSM, but hints of SUSY from $\tilde{g}$ and $\tilde{t}$ are there. Could be a puzzle, but in $\lambda$SUSY this is natural.
Properties of H

Heavy Higgs

$m_H \simeq 400 - 800 \text{GeV}$

$\Gamma_H \sim \text{few} - 20 \text{GeV}$

Production is suppressed because

- $g_{HVV} \simeq 0.1 - 0.3 \cdot g_{HVV}^{SM}$
- $g_{Htt} \simeq 0.1 - 0.5 \cdot g_{Htt}^{SM}$

Decay $H \rightarrow hh$ is very natural in $\lambda \text{SUSY}$

mostly due to:

- $H \rightarrow hh$ (gray areas)
- $H \rightarrow VV$ (black area)
Cross Section (HIGLU,VV2H)

\[ \sigma_{GF} \approx 50 \text{fb} - 300 \text{fb} \]

\[ \sigma_{VBF} \approx 5 \text{fb} - 100 \text{fb} \]
Can use we use $H \rightarrow hh$ to discover H?

- $H \rightarrow VV$ otherwise

**Benchmark scenario:**

- $\tan \beta = 2$
- $m_{H^\pm} = 500\text{GeV}$

- $\sigma_H^{GF} \times BR = 2.4\text{fb}$

- $m_H = 555\text{GeV}$, $\Gamma_H = 21\text{GeV}$

- $m_h = 250\text{GeV}$, $\Gamma_h = 3.8\text{GeV}$
We assume at this time $m_h$ has been measured

### Invariant mass requirements

- 2 jets reconstruct a vector if $m_{jj}$ is in $m_V \pm 8\text{GeV}$
- 4 fermions reconstruct a higgs if $m_{4f}$ is in $m_h \pm 33\text{GeV}$

### Relevant backgrounds

- $Z6j : 1\text{pb} \rightarrow 0.9\text{fb}$ (AlpGen)
- $t\bar{t}Z : 6\text{fb} \rightarrow 0.15\text{fb}$ (Madgraph)

### Event selection

- $\Delta R_{jj} > 0.7 \quad p_T^j > 20\text{GeV}$
- $\Delta R_{lj} > 0.1 \quad p_T^l > 10\text{GeV}$
- $\eta_e, l < 2.5$
- $80\text{GeV} < m_{ll} < 100\text{GeV}$
**S+BG vs BG**

- **Differential Cross Section**
  - **Integral**: 948.8

- **Final State Invariant Mass**
  - **Integral**: 948.8

**Smearing of jets 4-vectors** using $\frac{0.5}{\sqrt{s}} + 0.03$ to generate the smearing

- Flavour tagging is not relevant

**BG norm. is conservative**

- PS and HAD are not taken into account

- BG peaks close to signal peak

- Extraction of BG from data could be not simple

100$fb^{-1} \Rightarrow 6.0\sigma$

- Local event excess is very clear

- $g_{Hhh} \sim \lambda^2 \Rightarrow \lambda SU$SY
Properties of $A$

**Pseudoscalar**

- $m_A = 500\text{GeV} - 800\text{GeV}$
- $\Gamma_A \sim 10\text{GeV}$
- $BR(A \rightarrow t\bar{t}) = 0.5 - 0.9$
- $BR(A \rightarrow hZ) = 0.07 - 0.4$

- $\sigma$ is few pb :-)
- $BR$ is subdominant :-(
**A → hZ → ZVV → 4j l^+ l^-**

**Event Selection**
- $\Delta R_{jj} > 0.4$ $p_T^j > 20\text{GeV}$
- $\Delta R_{lj} > 0.4$ $p_T^l > 10\text{GeV}$
- $\eta_{j,l} < 2.5$
- $80\text{GeV} < m_{ll} < 100\text{GeV}$

**Invariant mass requirements**
Same strategy as for $H$ but now $\delta_{m_h} = 18\text{GeV}$

**BS:** $\tan \beta = 2$ $m_{H^\pm} = 500\text{GeV}$

$$\sigma_A^{GF} \times BR = 5.5\text{fb}$$

$m_A = 615\text{GeV}$, $\Gamma_A = 11\text{GeV}$

$m_h = 250\text{GeV}$, $\Gamma_h = 3.8\text{GeV}$

**Relevant backgrounds**
- $Z4j$ (AlpGen)
- $ZW2j$ (AlpGen)
S+BG vs BG

Differential cross section [fb]

PS and HAD are not taken into account.

\[ 100 fb^{-1} \Rightarrow 6.2\sigma \]

- Local event excess is very clear
- Peak is very clear
- A fit of the BG from data seems feasible

- Smearing of jets 4-vectors using \( \frac{0.5}{\sqrt{E}} + 0.03 \) to generate the smearing
- Flavour tagging is not relevant

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Conclusions

**SUSY can be out there even with a heavy higgs**

\( m_h \) will discriminate between MSSM-like and \( \lambda \) SUSY-like

\[
A \rightarrow hZ \rightarrow 2 VZ \rightarrow 4 j l^+ l^-
\]

and

\[
H \rightarrow hh \rightarrow 4 V \rightarrow 6 j l^+ l^-
\]

have been studied as possible signature of \( \lambda \) SUSY (large \( g_{Hhh} \) is very peculiar)

\( \tilde{g}, \tilde{t} \) and LSP pheno still available

**A and H observable at the LHC in high multiplicity final state**

- 100 fb\(^{-1}\) could be enough to observe \( A \) and \( H \)
- a large \( Hhh \) coupling is natural in \( \lambda \) SUSY

\[
m_h, m_H, m_A \Rightarrow \tan \beta, m_{H^\pm}, \lambda
\]

- \( \lambda \) allows to estimate the NP scale
- A fourth measurement like \( m_{H^\pm} \) or other decays would be a test for the theory