Higgs Decays and Missing Energy Signatures

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Work in Progress

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Introducing New Light Particles

- Particle models can be extended by new light particles near bottom of spectrum

- Hints for existence suggested by both data and naturalness

- Alters decays of heavier particles – motivates adaptive collider searches
Light Particle Profile

- Constraints require
  - Neutral
  - Weakly Interacting

- Unknowns
  - Spin?
  - Couplings?
  - Stable?
Opening New Decay Channels

Most Crucial For Narrow Width Particles
Motivations (Higgs)

• Lighter Higgs mass (below LEP2 limit)
  – Alleviates SUSY Little Hierarchy
  – Improves Precision Electroweak Fit (esp. as top mass central value continues to decrease)

• For e.g., adding a new scalar $a$ adds new dominant nonstandard Higgs decays;
  $h \rightarrow 2a \rightarrow 4\tau$ allows Higgs mass $< 100$ GeV (LEP2)

Dermisek, Gunion
Chang, Fox, Weiner
Graham, Pierce, Wacker

See Gunion talk for more details
An Interesting Twist

• Ingredient: a parity (e.g. R-parity), where the new light particle is parity odd

• This has a drastic effect on all other parity-odd particles, this modification must alter their decays

• In this case, there are reduced limits for both Higgs searches as well as the new particles

D.J. Miller
SUSY Example

MSSM
+ new neutralino $\chi_0$
(NMSSM & other extensions)

Invisible $2\chi_0$ decay strongly constrained

Higgs allowed below 114.4 GeV?

However, with RPV see Kaplan et.al.
Mini-Outline

What are constraints on

Higgs decays (LEP2)?

Squarks (Tevatron)?
Constraints on Higgs Mixed Neutralino Decay

- LEP2 – Higgs produced with Z
- Constraints depend on decays of $\chi_1$
- Depends on non-Higgs searches with similar topologies, so constraints are only estimates
- Different signal assumptions: 1) optimized cuts or 2) use likelihoods based on signal
Effective Cross Sections

Higgs Missing Energy Constraints
Strongest from LEP2 SUSY Searches

To apply constraints to Higgs, take
\[ Z \rightarrow \text{invisible} \]
\[ h \rightarrow 2\chi_0 f\bar{f} \]

Higgstrahlung not kinematically open for all luminosity of the different analyses
SUSY Searches (jets+ME)

b decays are strong, 2 body decay into scalar allowed only if BR is not O(1)

sbottom to b $\chi$ xs UL, 192-208 GeV

stop to c $\chi$ xs UL, 192-208 GeV

Sbottom Search
strong < .02 pb

General Squark
Weaker < .06 pb
Slepton Searches (leptons + ME)

- **Staus**
  - Observed Cross Section U.L. (pb)
  - $\sqrt{s} = 183-208$ GeV
  - ADLO Preliminary
  - taus $< .05$ pb
  - electrons $< .03$ pb
  - muons $< .03$ pb

- Taus and off-shell Z decays allow O(1) BR to neutralinos
Higgs Limit

100 GeV Higgs seems allowed for

\[ \text{BR}(\chi_1 \chi_0) \sim 1 \]  for decays into light quarks, leptons

\[ \text{BR}(\chi_1 \chi_0) \sim 0.3 \]  for all modes
Neutralino Properties

- Chargino search constraint, $> 100$ GeV
  - Requires a new singlet Weyl Fermion (Singlino) $\rightarrow$ NMSSM?

- Z Invisible Width and Neutralino Production at LEP
  - If $\tan \beta > 1$, $\chi_1$ is mostly bino and $\chi_0$ is mostly singlino

- Dark Matter Abundance: No Overclosure
  - A new light scalar of mass about $2m\chi_0$

\[ h \quad 90-110 \text{ GeV} \quad \chi_1 \quad 40-60 \text{ GeV} \quad \chi_0 \quad 1-20 \text{ GeV} \]
Note: Before Higgs constraints Spectral Information qualitatively the same

BR(h→χ₀χ₁) [0, 1]
Impact on SUSY Pheno

- Dominant singlino LSP implies longer cascades, potentially displaced vertices
- Longer cascades mean more visible energy (jets, leptons) and reduced missing energy
- Searches normally expect:
  - Squark $\rightarrow$ jet + MET
  - Gluino $\rightarrow$ 2jets + MET
- Effects degrade search esp. with optimized MET cuts
Tevatron Limits

Squark decays are actually more sensitive to dedicated gluino search

Missing Energy signature suppressed, e.g.

As $m_a$ approaches $m_{\chi_1}$, missing energy is reduced
Very Preliminary Results (DØ 2jet)

Note: All efficiencies simulated using PYTHIA, under onshell scalar assumption
VERY preliminary!!!
Only LO production xsecs, PROSPINO has alpine issues... NEAL still climatizing...
No combination of different analyses (overlapping events?)

\[ \varepsilon_{\text{squark}} \sigma_{\text{squark}} \]
\[ \varepsilon_{\text{D}0} \sigma_{\text{D}0 \text{ limit}} \]
Very Preliminary Results (DØ 3jet)

\[ \frac{\varepsilon_{\text{squark}} \sigma_{\text{squark}}}{\varepsilon_{\text{Do}} \sigma_{\text{Do limit}}} \]

Squark Mass

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Very Preliminary Results (DØ 4jet)

\[ \frac{\varepsilon_{\text{squark}}}{\varepsilon_{\text{Dø}}} \frac{\sigma_{\text{squark}}}{\sigma_{\text{Dø limit}}} \]
Squark Handles

Higgs constraints suggest additional leptons and/or light jets, perhaps through offshell Z's. Perhaps b's at reduced rate.

Left handed squarks decay into chargino which decay into onshell W's into $\chi_0$. 
Analysis Goals

- Understand Tevatron search efficiencies for this type of SUSY spectra
- Prelim. ~ 50-60 GeV weakening in DØ squark limits (~80 GeV for 310 pb⁻¹ analysis and offshell Z)
- Implement/Interpret CDF results
- Find distinctive features of these decays (leptons, W's likely)
- Motivates additional/adapted experimental searches that are sensitive to such “tags”
Other Scenarios

Sneutrinos
Helps with Dark Matter Abundance
Realizes off-shell Z scenario
R-parity

Neutrinos
Lepton Number is “Parity”
Off-shell Z's
Heavy particles affected are the heavy neutrinos
Conclusions

- New light particle suggested by naturalness and data in Higgs sector
- New light particle, odd under a parity, changes decays for all heavier odd parity states
- Discovery of both the heavy and light particles could require studies of such scenarios
- Finding Higgs and new Heavy States (e.g. Squarks) could require adapted searches
- For SUSY, cascades of squarks are extended, with more visible products, degraded MET
Conclusions (cont.)

- Higgs detectable? Need ideas/studies...
- Many opportunities persist for Tevatron Squark searches
  - Lepton pairs
  - W's from charginos in cascade
Early Results (DØ 2jet)

Note: All efficiencies simulated using PYTHIA, under offshell Z assumption

\[
\frac{\varepsilon_{\text{squark}} \sigma_{\text{squark}}}{\varepsilon_{\text{D0}} \sigma_{\text{D0 limit}}}
\]
Early Results (DØ 3jet)

\[ \frac{\varepsilon_{\text{squark}}}{\sigma_{\text{squark}}} \]

\[ \frac{\varepsilon_{\text{D0}}}{\sigma_{\text{D0}} \text{ limit}} \]

Squark Mass

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Early Results (DØ 4jet)

\[ \frac{\varepsilon_{\text{squark}}}{\sigma_{\text{squark}}} \]

\[ \frac{\varepsilon_{\text{D0}}}{\sigma_{\text{D0 limit}}} \]

Squark Mass

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