# The Interplay between Higgs and squark-gluino events at the LHC.

Amitava Datta

IISER, Kolkata, India

**WORK DONE WITH IN COLLABORATION WITH**

**Nabanita Bhattacharyya (IISER KOLKATA)**

**Monoranjan Guchait (TIFR)**

**Manas Maity (Visva-Bharati University)**

**Sujoy Poddar (Netaji Nagar Day college)**

**arXiv:1007.0635, Accepted for publication in PRD**

# Introduction

SM : Single Neutral Higgs boson

Discovery of two neutral/ one or more charged Higgs boson at the LHC

$\longrightarrow$ Physics beyond SM

Utmost care is needed for H -Search

# Introduction

Different search strategies proposed for H - Search

All takes care of the SM background only

In many BSM an extended Higgs sector comes with other new particles

Can these new particle production obfuscate the Higgs Signal ?

# Introduction

In MSSM the H -boson come with many sfermions and gauginos

Squarks and gluinos being strongly interacting sparticles have large production rate

Can they obfuscate/mimic the H -Signal ?

# Introduction

In MSSM there are FIVE Higgs particles

- Two CP -even neutral (scalar) particles : $h$, $H$
- One CP -odd neutral (pseudoscalar) particle :$A$
- Two charged particles: $H^{\pm}$

In order to describe the MSSM Higgs sector one needs :

- $M_A$ and $tan\beta$

# Introduction

Tree level masses :

$$M^2_{H,h} = \frac{1}{2}[M^2_A + M^2_Z \pm \sqrt{(M^2_A + M^2_Z)^2 - 4M^2_Z M^2_A cos^2 2\beta}]$$

$$M^2_{H\pm} = M^2_A + M^2_W$$

Thus at tree level

- $M_h < M_Z$, $M_A < M_H$ and $M_W < M_{H^\pm}$

# Introduction

MSSM Higgs search is most challenging in the Deep Decoupling Region
$M_A \gg M_Z$

$h$ indistinguishable from $h^{SM}$

$H$, $A$, $H^{\pm}$ are heavy ( mass $\sim M_A$)

Small production cross section

We focus on this region

# Introduction

Illustrate the Interplay between the Higgs and the squark-gluino sector by considering the Charged Higgs signal

$gb \longrightarrow tH^{\pm} + h.c$

$H^{+} \longrightarrow t\bar{b}$ : suffers from a large QCD background

$H^{\pm} \longrightarrow \tau^{\pm}\nu_{\tau}$

This Branching Fraction $\geq 10\%$ for $tan\beta \geq 10$

# Introduction

Therefore SIGNAL consists of :

- One tagged $\tau$ -jet
- One tagged $b$ -jet
- One reconstructed top
- One reconstructed $W$
- Missing Energy

# Introduction

Main SM background $t\bar{t}$

One top decays : $t \longrightarrow bqq'$

Other top decays : $t \longrightarrow bW \longrightarrow b\tau\nu_\tau$

Other backgrounds to be discussed

SUSY can give similar final state

For example:

$\tilde{g} \longrightarrow \tilde{t}_1 t$

$\tilde{t}_1 \longrightarrow b\widetilde{\chi}_1^{\pm}$

$\widetilde{\chi}_1^{\pm} \longrightarrow \widetilde{\tau}_1 \nu_\tau$

$\widetilde{\tau}_1 \longrightarrow \tau\widetilde{\chi}_1^0$

# SUSY scenarios

$tan\beta = 40$, $\mu = 500$
$m_{\tilde{q}_{L,R}} = 1000 + D - term$, $m_{\tilde{g}} = 560$, $m_{\tilde{e}_{L,R}} = 303$, $m_{\tilde{\nu}_L} = 293$.
$m_{\tilde{\chi}_1^0} = 149$, $m_{\tilde{\chi}_2^0} = 298$, $m_{\tilde{\chi}_1^+} = 298$.
The masses for 3rd generation sfermions are fixed by the following parameters:
$m_{t_L, b_L} = 600$, $m_{b_R} = 500$, $m_{\tau_L, \tau_R} = 250$, $A_t = -900$, $A_b = -900$, $A_\tau = -500$.
SUSY I, II and III characterized by $m_{\tilde{t}_R}$=350, 400, 453 $GeV$

| Model | $m_{\tilde{t}_1}$ | $m_{\tilde{t}_2}$ | $m_{\tilde{b}_1}$ | $m_{\tilde{b}_2}$ | $m_{\tilde{\tau}_1}$ | $m_{\tilde{\tau}_2}$ |
|---|---|---|---|---|---|---|
| SUSY I | 306 | 677 | 500 | 630 | 215 | 378 |
| SUSY II | 353 | 683 | 500 | 630 | 215 | 378 |
| SUSY III | 397 | 690 | 500 | 630 | 215 | 378 |

# Branching Ratios

| channels | SUSY I | SUSY II | SUSY III |
|---|---|---|---|
| $\tilde{g} \to \tilde{t}_1 t$ | 0.80 | 0.61 | – |
| $\tilde{g} \to \tilde{b}_1 b$ | 0.18 | 0.38 | 1.0 |
| $\tilde{t}_1 \to \widetilde{\chi}_1^+ b$ | 1.0 | 0.40 | 0.47 |
| $\tilde{t}_1 \to \widetilde{\chi}_1^0 t$ | – | 0.60 | 0.52 |
| $\tilde{b}_1 \to \widetilde{\chi}_1^0 b$ | 0.29 | 0.34 | 0.39 |
| $\tilde{b}_1 \to \widetilde{\chi}_2^0 b$ | 0.26 | 0.31 | 0.35 |
| $\tilde{b}_1 \to \widetilde{\chi}_1^+ t$ | 0.17 | 0.20 | 0.23 |
| $\tilde{b}_1 \to \tilde{t}_1 W$ | 0.27 | 0.15 | 0.33 |

In all cases the $BR(\widetilde{\chi}_1^\pm \to \widetilde{\tau}_1 \nu_\tau) = 0.89$ and $BR(\widetilde{\chi}_2^0 \to \widetilde{\tau}_1 \tau) = 0.9$

# SUSY Scenarios

SUSY VI - VIII

Gluino mass increased :

$m_{\tilde{g}}$ = 790, 950 $GeV$ $\quad m_{\tilde{g}} < m_{\tilde{q}}$

$m_{\tilde{g}}$ = 1020, 1180 and 1345 $GeV$ $\quad m_{\tilde{g}} > m_{\tilde{q}}$

Keeping third generation sfermions masses fixed

$m_{\tilde{b}_1} = 755$, $m_{\tilde{b}_2} = 980$, $m_{\tilde{t}_1} = 751$, $m_{\tilde{t}_2} = 1007$, $m_{\tilde{\tau}_1} = 215$, $m_{\tilde{\tau}_2} = 378$.

# Dark matter allowed mSUGRA point

mSUGRA point consistent with the Dark matter data

$m_0 = 230, m_{1/2} = 420, A_0 = 0, \tan\beta = 40, sign(\mu) > 0$

The resulting mass spectrum : $m_{\tilde{u}_L} = 918$, $m_{\tilde{d}_L} = 922$, $m_{\tilde{u}_R} = 888$, $m_{\tilde{d}_R} = 886$, $m_{\tilde{g}} = 977$, $m_{\tilde{b}_1} = 788$, $m_{\tilde{b}_2} = 849$, $m_{\tilde{t}_1} = 694$, $m_{\tilde{t}_2} = 866$, $m_{\tilde{e}_L} = 365$, $m_{\tilde{e}_R} = 280$, $m_{\tilde{\nu}_L} = 356$. $m_{\tilde{\tau}_1} = 182$, $m_{\tilde{\tau}_2} = 370$, $m_{\tilde{\chi}_1^0} = 171$, $m_{\tilde{\chi}_2^0} = 323$, $m_{\tilde{\chi}_1^+} = 322$. $m_{H^\pm} \approx 500$.

This is not a tuned scenario.

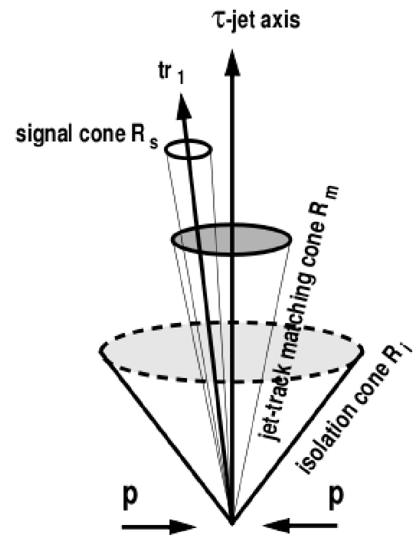
# Dark matter allowed mSUGRA point

In this scenario the relevant BRs are BR($\tilde{g} \to t\tilde{t}_1$)=20 $\%$, BR($\tilde{g} \to b\tilde{b}_1$)= 26 $\%$, BR($\widetilde{\chi}_1^+ \to \widetilde{\tau}_1 \nu_\tau$)= 95 $\%$ and BR($\widetilde{\chi}_2^0 \to \widetilde{\tau}_1 \tau$)= 94 $\%$.

The DM relic density $\Omega = .12$

The neutralino bulk annihilation contributes 37$\%$ to the relic density whereas $\widetilde{\chi}_1^0 - \widetilde{\tau}$ coannihilation contributes 63$\%$.

# $\tau$ jet identification




Signal cone $\Delta R_S = 0.1$ ; Isolation cone $\Delta R_I = 0.4$
1 or 3 charged tracks inside signal cone
$|\eta_{track}| < 2.5$; $P_T >$ 3 GeV for the hardest track
No charged track $P_T >$ 1 GeV inside Isolation cone

# TOP and W reconstruction

- Invariant mass of any two jets; jets $\neq \tau$ or $b$-jet $\Rightarrow$ W candidate
- $b$-jet combined with a W candidate $\Rightarrow$ Top candidate
- $\chi^2$ Minimization done, where

  $$\chi^2_{top} = \left(\frac{m_W - m_W^{rec}}{15}\right)^2 + \left(\frac{m_t - m_t^{rec}}{25}\right)^2$$

# Analysis

Following standard Selection Criteria used for background rejection:

- One tagged $b$-jet.
- One identified $\tau$-jet.
- One detected $\tau$-jet with $E_T^{\tau-jet} > 100\ GeV$.
- $\not{E}_T > 100\ GeV$.
- njets $\geq$ 3 (except $\tau$ jet).
- One reconstructed top.
- $\Delta\phi(\tau - jet, \not{E}_T) > 60^\circ$.

# Results

| | | Signal $m_{H^\pm}$ (GeV) | | | | $t\bar{t}$ | QCD | $W+3j$ |
|---|---|---|---|---|---|---|---|---|
| | | 500 | 600 | 700 | 800 | | | |
| | $\sigma$ (pb) | 0.67 | 0.36 | 0.20 | 0.12 | 492 | 2042 | 46.65 |
| | Selections | | | | | | | |
| Cut 1 | $1\ b-jet$ | 0.539 | 0.540 | 0.545 | 0.546 | 0.486 | 0.0745 | 0.266 |
| Cut 2 | $1\ \tau-jet$ | 0.210 | 0.216 | 0.219 | 0.218 | 0.112 | 0.0017 | 0.005 |
| Cut 3 | $E_T^{\tau-jet} > 100$ GeV | 0.142 | 0.158 | 0.169 | 0.172 | 0.0086 | $3.7\times10^{-5}$ | $4.6\times10^{-4}$ |
| Cut 4 | $\not\!\!E_T > 100$ GeV | 0.118 | 0.137 | 0.152 | 0.157 | 0.0023 | $7.7\times10^{-5}$ | $9.5\times10^{-5}$ |
| Cut 5 | $N_{jet} \geq$ 3(except $\tau$-jet) | 0.076 | 0.089 | 0.098 | 0.102 | 0.0021 | $6.1\times10^{-5}$ | $8.2\times10^{-5}$ |
| Cut 6 | 1 reconstructed top | 0.054 | 0.061 | 0.066 | 0.069 | 0.0015 | $9.0\times10^{-6}$ | $2.1\times10^{-5}$ |
| Cut 7 | $\Delta\phi(\tau-jet, \not\!\!E_T) > 60^\circ$ | 0.051 | 0.058 | 0.064 | 0.067 | $1.5\times10^{-4}$ | $6.0\times10^{-6}$ | - |
| | $\sigma \times \epsilon_1$ (fb) | 4.2 | 2.5 | 1.4 | 0.8 | 11.2 | 12.3 | - |
| Cut 8 | $E_T^{\tau-jet} > 180$ GeV | 0.025 | 0.036 | 0.045 | 0.050 | $2.2\times10^{-5}$ | - | - |
| Cut 9 | $\not\!\!E_T > 260$ GeV | 0.0033 | 0.011 | 0.020 | 0.028 | $1.0\times10^{-6}$ | - | - |
| | $\sigma \times \epsilon_2$ (fb) | 0.27 | 0.47 | 0.45 | 0.34 | 0.07 | - | - |
| Cut 10 | $N_{jet} \leq 6$ | 0.0028 | 0.0095 | 0.0181 | 0.0251 | – | – | – |
| | $\sigma \times \epsilon_3$ (fb) | 0.24 | 0.41 | 0.40 | 0.30 | – | – | – |

# Results

| | SUSY I | SUSY II | SUSY III |
|---|---|---|---|
| $\sigma$ (pb) | 12.2 | 10.1 | 8.9 |
| $m_{\tilde{t}_1}$ | 306 | 353 | 398 |
| 1 $b - jet$ | 0.32982 | 0.31205 | 0.24578 |
| 1 $\tau - jet$ | 0.04088 | 0.03905 | 0.02912 |
| $E_T^{\tau-jet} > 100$ GeV | 0.00384 | 0.00379 | 0.00381 |
| $\not{E}_T > 100$ GeV | 0.00322 | 0.00294 | 0.00323 |
| $N_{jet} \geq 3$ (except $\tau$-jet) | 0.00308 | 0.00281 | 0.00309 |
| 1 reconstructed top | 0.00220 | 0.00204 | 0.00166 |
| $\Delta\phi(\tau - jet, \not{E}_T) > 60^\circ$ | 0.00129 | 9.1 $\times 10^{-4}$ | 8.5 $\times 10^{-4}$ |
| $\sigma \times \epsilon_1$ (fb) | 15.7 | 9.2 | 4.7 |
| $E_T^{\tau-jet} > 180\ GeV$ | 2.0$\times 10^{-4}$ | 1.9$\times 10^{-4}$ | 1.3$\times 10^{-4}$ |
| $\not{E}_T > 260\ GeV$ | 7.0$\times 10^{-5}$ | 8.0$\times 10^{-5}$ | 3.0$\times 10^{-5}$ |
| $\sigma \times \epsilon_2$ (fb) | 0.85 | 0.80 | 0.19 |
| $N_{jet} \leq 6$ | 1.0$\times 10^{-5}$ | 1.0$\times 10^{-5}$ | 1.0$\times 10^{-5}$ |
| $\sigma \times \epsilon_3$ (fb) | 0.12 | 0.10 | 0.09 |

# New Cuts

The standard cuts cannot tame the SM backgrounds even if the SUSY bkgd is negligible.

In the literature additional cuts have been proposed to tame the SM bkgd only.

$\tau$-polarisation is one such criteria used by many groups.

# New Cuts

Motivation :

- A $\tau^-$ from $H^-$ decay is R-polarised
  A $\tau^-$ from $W^-$ decay is L-polarised
- Fraction of $\tau$-jet energy carried by decay products is very different
- The same cut also kills the QCD background (arising from mistagging of light jets as $\tau$ jets).

# New Cuts

The polarization of the $\tau$'s appearing in squark-gluino decay cascade has much more variety and can be very similar to the $\tau$ from H-decay.

Example: Most of the $\tau$'s may come from $\widetilde{\tau}_1$ decay.
$\widetilde{\tau}_1 \rightarrow \tau \widetilde{\chi}_1^0$

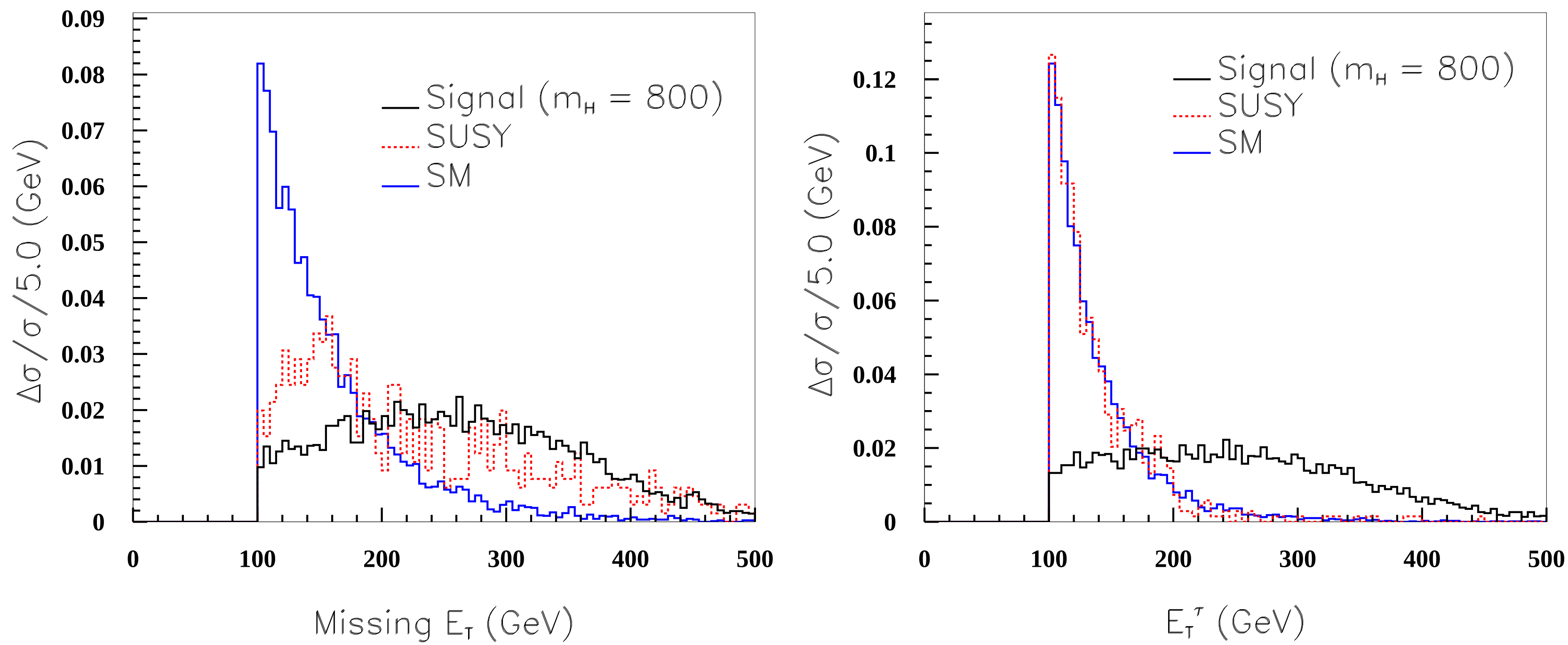
if $\widetilde{\tau}_1$ is $\widetilde{\tau}_R$ dominated and
the $\widetilde{\chi}_1^0$ is $\tilde{B}$ dominated
then most of the $\tau$'s in the decay cascade are R-polarized.

# New Cuts

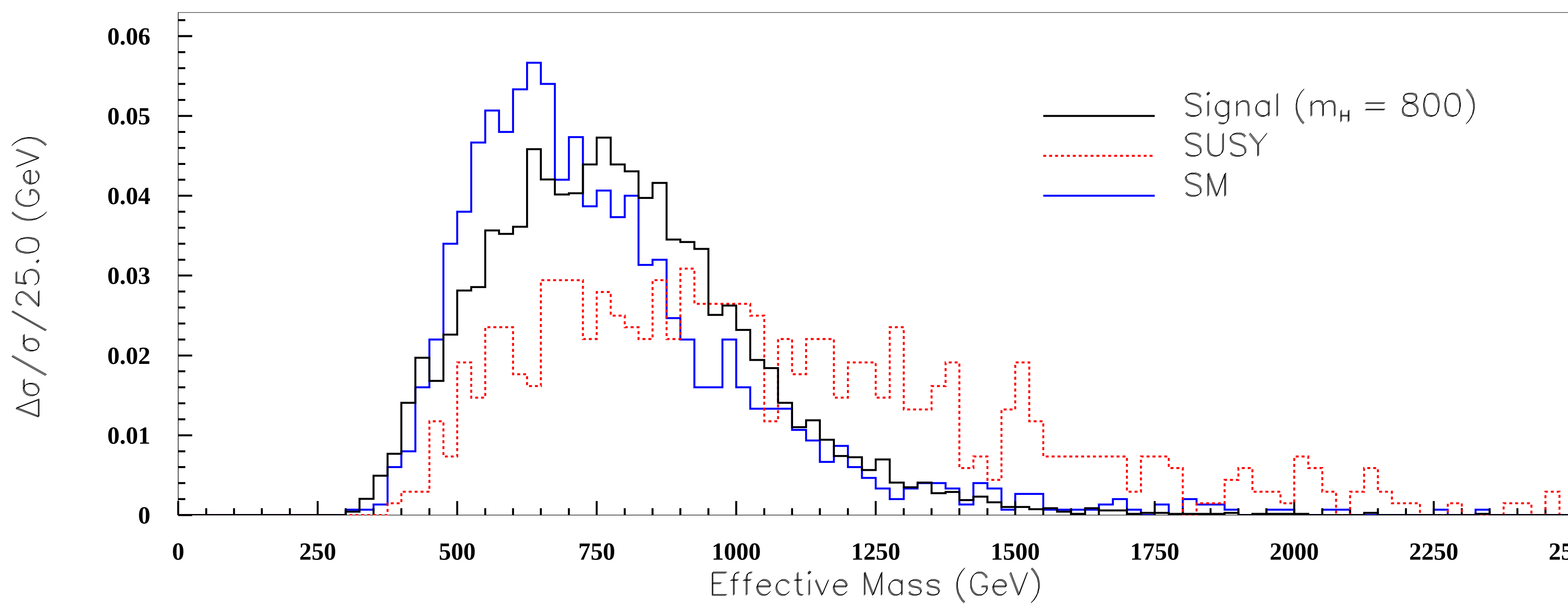
This is also the case in mSUGRA over most of the parameter space.

Better to think of more generic cuts which does not depend crucially on the composition of the $\widetilde{\tau}_1$ and the neutralinos.

# Distribution



# Distribution



# Analysis

Stronger selection cuts to suppress $t\bar{t}$, QCD and SUSY :

- $E_T^{\tau-jet} > 180 GeV$.
- $\not{E}_T > 260 GeV$.

# Analysis

Finally to isolate $H^{\pm}$ from squark-gluino events:

- option 1: $N_{jet} \leq$ 6.
- option 2: Veto events with a isolated lepton with $P_T^{e,\mu} > 15$ GeV and $|\eta| \leq 2.4$.
- option 3: $M_{eff} < 800 GeV$, where $M_{eff} = |\not{E}_T| + \Sigma_i |P_T^{l_i}| + \Sigma_i |P_T^{j_i}|$ ($l = e, \mu$).
- option 4: $N_{jet} \leq$ 5.
- option 5: $N_{jet} \leq$ 6 and $N_{lep} = 0$.

# Results

Isolation of $H^{\pm}$ signal from squark-gluino events (SUSY I):

| Cuts | $m_{H^{\pm}}$ (GeV) | | | |
|---|---|---|---|---|
| | 500 | 600 | 700 | 800 |
| | $S/\sqrt{B}$ | | | |
| $N_{jet} \leq 6$ | 4.0 | 6.5 | 6.3 | 5.0 |
| $N_{lep} =0$ | 2.0 | 3.6 | 3.4 | 2.5 |
| | Background free number of signal events | | | |
| $M_{eff} < 800$ GeV | 5 | 7 | 5 | 3 |
| $N_{jet} \leq 5$ | 6 | 10 | 10 | 7 |
| $N_{lep} =0$ and $N_{jet} \leq 6$ | 6 | 11 | 10 | 7 |

# Results

SUSY IV -V : $m_{\tilde{g}} < m_{\tilde{q}}$

SUSY VI -VIII : $m_{\tilde{g}} > m_{\tilde{q}}$

| | SUSY IV | SUSY V | SUSY VI | SUSY VII | SUSY VIII |
|---|---|---|---|---|---|
| $m_{\tilde{g}}$(GeV) | 790 | 950 | 1020 | 1180 | 1345 |
| $\sigma$(pb) | 5.6 | 3.8 | 0.88 | 0.61 | 0.49 |
| $\sigma \times \epsilon_1$(fb) | 5.9 | 3.1 | 1.5 | 0.60 | 0.38 |
| $\sigma \times \epsilon_2$(fb) | 0.34 | 0.30 | 0.31 | 0.12 | 0.11 |
| $\sigma \times \epsilon_3$(fb) | 0.11 | 0.038 | 0.079 | 0.037 | 0.049 |

# Results

## Dark matter allowed mSUGRA point

$m_0 = 230, m_{1/2} = 420, A_0 = 0, \tan\beta = 40, sign(\mu) > 0$

| | |
|---|---|
| $\sigma$ (pb) | 1.5 |
| $\sigma \times \epsilon_1$(fb) | 1.35 |
| $\sigma \times \epsilon_2$(fb) | 0.45 |
| $\sigma \times \epsilon_3$(fb) | 0.15 |

# Conclusion

- Higgs and other new physics events may have many features in common.
- Thus the standard selection criteria for eliminating the SM backgrounds in Higgs search may leave behind an admixture of Higgs and new physics events unless special care is taken to eliminate the latter.
- We illustrate this by the charged Higgs signal in the MSSM in the decoupling regime ($M_A >> M_Z$).
- The $\tau$-polarization which is often used to eliminate the SM background may not work for the SUSY background.
- We introduced several new criteria to tame the generic SUSY background but yield a reasonable charged Higgs signal.

# Conclusion

For Higgs search the analysis of this paper recommends a three step procedure

- In the first step the cuts designed to suppress the SM background (similar to Cuts 1-7) should be applied.

  Higgs + New Physics Signal may already reveal BSM Physics

  A Two Higgs doublet extension of the SM with comparable $H^{\pm}$ cross-section will be disfavoured

# Conclusion

- The second stage should consist of additional cuts (like Cuts 8-9) which may control both SM and BSM backgrounds.

- Finally especially designed cuts (like Cut 10 or its alternatives suggested) to kill the BSM background should be employed.

If the number of observed events reduce drastically after Cut 10 that would provide hints for new physics.

THANK YOU