

The interplay between the Charged Higgs and Supersymmetry events at the LHC(14 TeV)

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Charged Higgs(H^\pm)

- Supersymmetric extension of Standard Model : **SM + $\tilde{S}\tilde{M}+2$ HD**
- Extended Higgs sector : **Needs two oppositely Hyper charged(+1 and -1) Higgs doublet** to cancel Chiral anomaly.(Minimal model)
- This two oppositely hyper charged Higgs doublets give masses also to up-type and down type quarks.
- Two Higgs doublet \Rightarrow 8 d.o.f present. After EWSB three are eaten by W^\pm, Z and 5 Higgs scalars: **h, H, A and H^\pm**
- **SUSY extension of the SM predict a physical H^\pm .**
Tree level: $m_{H^\pm}^2 = m_W^2 + M_A^2$; Radiative corrections: Large for $\tan\beta < 1$, less for $\tan\beta > 1$, $\delta m_{H^\pm} \sim$ few GeV. Tree level gives good description. CPV SUSY can give large corrections.
- The H^\pm carries the unambiguous hallmark of the MSSM Higgs sector \Rightarrow **New Physics**

Supersymmetry signal at LHC

- LHC is a QCD dominated machine.
 - $pp \rightarrow \tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q} \rightarrow \tilde{\chi}_1^\pm, \tilde{\chi}_2^0 + jets + \cancel{E}_T$
 - Generic signal : leptons + jets + \cancel{E}_T
 - Leptons may be e, μ or τ 's, depending on the parameter space, **See talk by Dipan Sengupta**
- $\tilde{\chi}_1^\pm \rightarrow \tilde{\nu} + l, \tilde{\ell} + \nu, \tilde{\tau}_1 + \nu; \tilde{\chi}_2^0 \rightarrow \tilde{\ell} + l, \tilde{\tau}_1 + \tau$
 $\tilde{\ell} \rightarrow l + \tilde{\chi}_1^0, \text{ and } \tilde{\tau} \rightarrow \tau + \tilde{\chi}_1^0;$
- Signal is e/μ or τ rich final states, depending on SUSY parameter space. **In this work we focused τ rich final states**

Interplay between Charged Higgs and SUSY signal

- **Charged Higgs:**

$$PP \rightarrow tH^- \rightarrow (bq\bar{q}')(\tau\nu_\tau) \rightarrow \underline{\text{"}\tau\text{"} + \text{jets} + X}$$

- **SUSY:**

$$PP \rightarrow \tilde{g}\tilde{g} \rightarrow (t\tilde{t}_1)(t\tilde{t}_1) \rightarrow (bq\bar{q}')(b\tilde{\chi}_1^\pm)(bq\bar{q}')(b\tilde{\chi}_1^\pm)$$

$$\Rightarrow \underline{\text{"}\tau\text{"} + \text{jets} + X} \quad (\tilde{\chi}_1^\pm \rightarrow \tilde{\tau}_1 + \nu_\tau; \tilde{\tau}_1 \rightarrow \tau + \tilde{\chi}_1^0)$$

- **SUSY might be a potential background in H^\pm detection.**

- **Charged Higgs events may increase the sensitivity of SUSY signal.**

- **SUSY events might fake as a Charged Higgs events (for high values of m_{H^\pm} .)**

Parameter Space dependence along with Charged Higgs signal is investigated

SUSY parameter space

General MSSM

$$m_{\tilde{q}_{L,R}} = 1000 + \text{appropriate D-term}, m_{\tilde{g}} = 560,$$
$$m_{\tilde{e}_{L,R}} = 303, m_{\tilde{\nu}_L} = 293.$$

Fixing $M_1 = 150$ GeV,

$$m_{\tilde{\chi}_1^0} = 149, m_{\tilde{\chi}_2^0} = 298, m_{\tilde{\chi}_1^\pm} = 298.$$

3rd Generation sector is fixed by,

$$m_{\tilde{t}_{L,\tilde{b}_L}} = 600, m_{\tilde{b}_R} = 500, m_{\tilde{\tau}_L} = 350, m_{\tilde{\tau}_R} = 250,$$
$$A_t = -900, A_b = -900, A_\tau = -500.$$

Scenarii SUSY I - III: $m_{\tilde{t}_R} = 350, 400, 455.$

SUSY IV - VIII: $m_{\tilde{g}} = 790, 950, 1020, 1180, 1345;$

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

Masses and Branching ratios

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

Channels	SUSY I	SUSY II	SUSY III
$\tilde{g} \rightarrow \tilde{t}_1 t$	0.80	0.61	–
$\tilde{g} \rightarrow \tilde{b}_1 b$	0.18	0.38	1.0
$\tilde{t}_1 \rightarrow \tilde{\chi}_1^\pm b$	1.0	0.40	0.47
$\tilde{t}_1 \rightarrow \tilde{\chi}_1^0 t$	–	0.60	0.52
$\tilde{b}_1 \rightarrow \tilde{\chi}_1^0 b$	0.29	0.34	0.39
$\tilde{b}_1 \rightarrow \tilde{\chi}_2^0 b$	0.26	0.31	0.35
$\tilde{b}_1 \rightarrow \tilde{\chi}_1^\pm t$	0.17	0.20	0.22
$\tilde{b}_1 \rightarrow \tilde{t}_1 W$	0.27	0.15	0.33

Signal and Backgrounds

- **Signal processes:**

$$PP \rightarrow tH^- \rightarrow (bq\bar{q}')(\tau\nu_\tau) \rightarrow \tau + jets + X$$

- **SM Backgrounds:**

$t\bar{t} \rightarrow (bq\bar{q}')(\mathbf{b}\tau\nu_\tau)$, QCD: soft jets faking as tau jets.

- **SUSY Backgrounds:**

$$PP \rightarrow \tilde{g}\tilde{g} \rightarrow (t\tilde{t}_1)(t\tilde{t}_1) \rightarrow (bq\bar{q}')(b\tilde{\chi}_1^\pm)(bq\bar{q}')(b\tilde{\chi}_1^\pm) \\ \Rightarrow \tau + jets + X$$

Calculations

- **PYTHIA** is used for analysis.

$Q^2 = \hat{s}$ and CTEQ5L is used for PDF.

Selections:

- $|\eta| < 4.5$ with segmentation of $\Delta\eta \times \Delta\phi = 0.09 \times 0.09$.
- A fixed cone algorithm with $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.5$.
- Jets are ordered: E_T with $E_{T,min}^{jet} = 20$ GeV.
- b-jet is tagged with $|\eta| < 4.5$ and with a B-hadron of decay length > 0.9 mm. In $t\bar{t}$ process efficiency ~ 0.5 .
- τ lepton is tagged through its hadronic decay mode, in one 1 or 3 prong decay mode, with $|\eta| < 2.5$ and $P_T > 3$ GeV for leading track. Tau isolation is checked with tracks $p_T > 1$ GeV ($\Delta R_S = 0.1$ and $\Delta R_I = 0.4$)
- top reconstruction is performed by χ^2 minimization.

CUTs

- **Cut 1: One tagged b -jet).**
- **Cut 2: One identified τ -jet.**
- **Cut 3: Events should have one detected τ -jet with $E_T^{\tau-jet} > 100$ GeV.**
- **Cut 4: Missing transverse energy $E_T' > 100$ GeV.**
- **Cut 5: At least three jets in addition to one extra τ jet in the event.**
- **Cut 6: One reconstructed top as described above (Cut 6).**
- **Cut 7: $\Delta\phi(\tau - jet, E_T') > 60^\circ$.**

Event Summary

	Signal m_{H^\pm} (GeV)				$t\bar{t}$	QCD	$W+3j$
	500	600	700	800			
σ (pb)	0.67	0.36	0.20	0.12	492	2042	46.65
Selections							
1b jet	0.539	0.540	0.545	0.546	0.486	0.0745	0.266
τ	0.210	0.216	0.219	0.218	0.112	0.0017	0.005
$E_T^{\tau-jet} > 100$	0.142	0.158	0.169	0.172	0.0086	3.7×10^{-5}	4.6×10^{-5}
$\cancel{E}_T > 100$	0.118	0.137	0.152	0.157	0.0023	7.7×10^{-5}	9.5×10^{-5}
$N_{jet} \geq 3$	0.076	0.089	0.098	0.102	0.0021	6.1×10^{-5}	8.2×10^{-5}
Reco top	0.054	0.061	0.066	0.069	0.0015	9.0×10^{-6}	2.1×10^{-6}
$\Delta\phi(\tau - jet, \cancel{E}_T) > 60^\circ$	0.051	0.058	0.064	0.067	1.5×10^{-4}	6.0×10^{-6}	-
$\sigma \times \epsilon_1$ (fb)	4.2	2.5	1.4	0.8	11.2	12.3	-

Event Summary:SUSY

	SUSY I	SUSY II	SUSY III
σ (pb)	12.2	10.1	8.9
$m_{\tilde{t}_1}$ (GeV)	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
$\cancel{E}_T > 100$ GeV	0.00322	0.00294	0.00323
$N_{jet} \geq 3$ (except τ -jet)	0.00308	0.00281	0.00309
1 reconstructed top	0.00220	0.00204	0.00166
$\Delta\phi(\tau - jet, \cancel{E}_T) > 60^\circ$	0.00129	9.1×10^{-4}	8.5×10^{-4}
$\sigma \times \epsilon_1$ (fb)	15.7	9.2	4.7
SM Bg \rightarrow	$t\bar{t}$	QCD	W+3jet
$\sigma \times \epsilon_1$ (fb)	11.2	12.3	-

	Signal m_{H^\pm} (GeV)			
	500	600	700	800
$\sigma \times \epsilon_1$ (fb)	4.2	2.5	1.4	0.8

H^\pm and SUSY events

- SUSY events are significant, even large(SUSY -I) than $t\bar{t}$ bg,also the weakest SUSY events SUSY-III is larger than H^\pm signal events.
- The SUSY + H^\pm together can appear as the total number of events signaling BSM physics, although H^\pm events are no longer very much favoured.
- The significance for SUSY I + H^\pm (=500 GeV), is 7.5 for $\mathcal{L} = 1 fb^{-1}$. Thus the BSM physics can be found at the early phase of LHC.
- For $m_{H^\pm} = 800$ GeV, higgs signal is too low, so, SUSY events can even fake as a charged Higgs signal. So, need some technique to disentangle the two type of events and confirm the charged Higgs signal.

Extra Cuts

- τ polarization cut is useful in charged Higgs signal, where it is right handed polarized, In SUSY case, mostly, τ come from $\tilde{\tau}_1$ decay. and mostly right ahnded polarized. However, polarization depend on the SUSY parameter space.
- In lieu of τ -polarization, two more hard cuts are applied:
 - **Cut 8: Stingent cut, $E_T^{\tau-jet} > 180$ GeV.**
 - **Cut 9: $E_T > 260$ GeV.**

Results with new cuts

	Signal m_{H^\pm} (GeV)				$t\bar{t}$	QCD	$W + 3j$
	500	600	700	800			
σ (pb)	0.67	0.36	0.20	0.12	492	2042	46.65
Cut 1-7 $\sigma \times \epsilon_1$ (fb)	4.2	2.5	1.4	0.8	11.2	12.3	-
Cut 1-9 $\sigma \times \epsilon_2$ (fb)	0.27	0.47	0.45	0.34	0.07	-	-

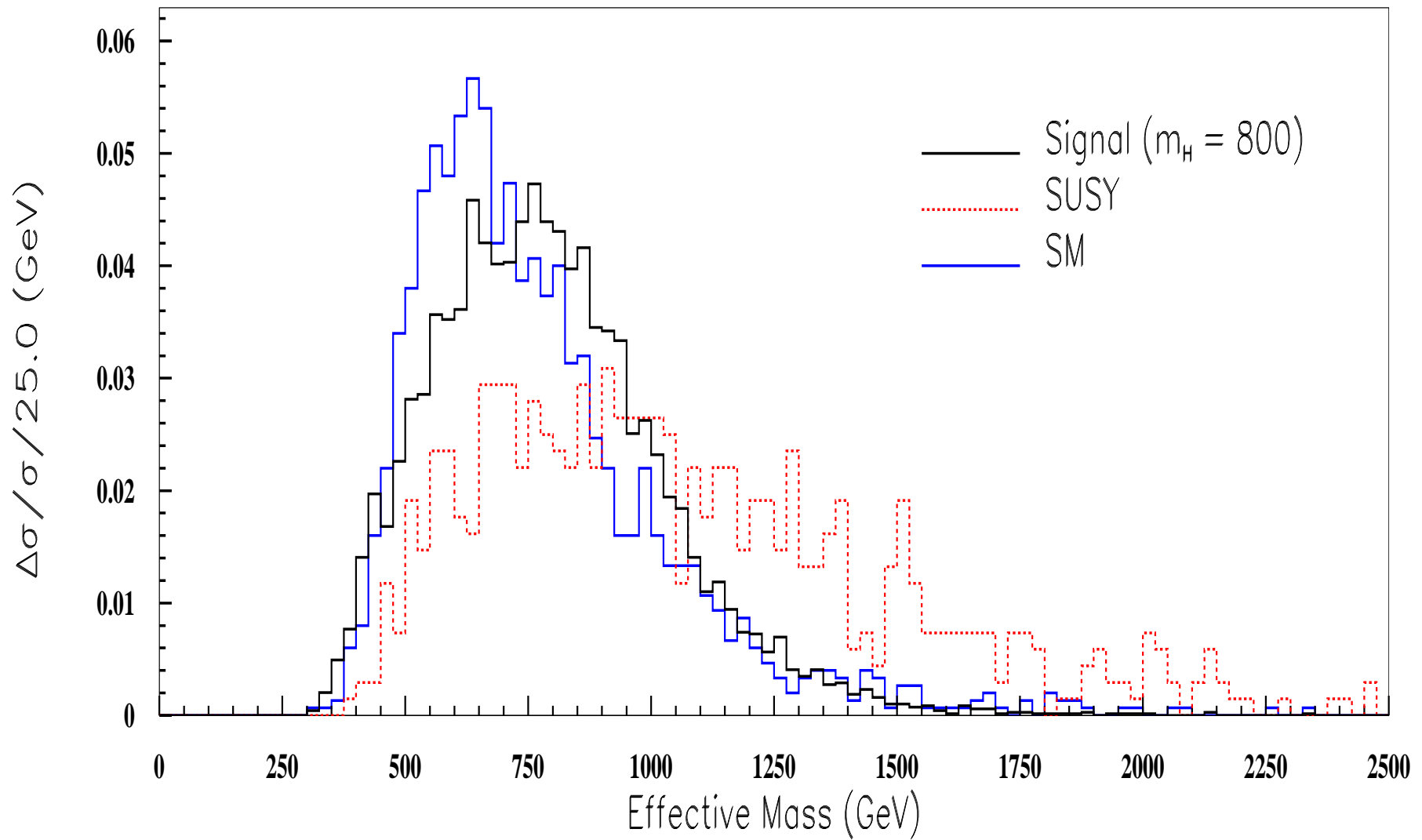
	SUSY I	SUSY II	SUSY III
σ (pb)	12.2	10.1	8.9
Cut 1-7 $\sigma \times \epsilon_1$ (fb)	15.7	9.2	4.7
Cut1-9 $\sigma \times \epsilon_2$ (fb)	0.85	0.80	0.19

- Fraction of Higgs signal improves over SUSY signal events.

Increase purity of Charged Higgs Signal

- H^\pm signal is still contaminated by the SUSY events. To increase the purity of the Higgs signal, apply more cuts:
- Cut 10: $N_{jet} \leq 6$
- For $\mathcal{L} = 30 fb^{-1}$.

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



$$\text{Effective mass, } M_{eff} = |E'_T| + \sum_i |P_T^{l_i}| + \sum_i |P_T^{j_i}| \quad (l = e, \mu)$$

Gluino mass reach

	SUSY IV	SUSY V	SUSY VI	SUSY VII	SUSY VIII
$m_{\tilde{g}}$ (GeV)	790	950	1020	1180	1345
σ (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

- The SUSY backgrounds for increasing $m_{\tilde{g}}$.

“Inverse Problem”

- The charged Higgs events may affect the canonical signature leptons+jets+ E_T signal.

WE restrict ourselves only 0 and 1 lepton final states.

- $P_T \geq 30$ GeV, $|\eta| \leq 2.5$. tau jets also considered $1\tau + X$ final states.
- Cut 1': Select events with at least two jets having $P_T > 150$ GeV.
- Cut 2': $(E_T) > 200$ GeV.
- Cut 3': $M_{eff} > 1000$ GeV.

	Selection Criteria	$0l$	$1l$	$1\tau + X$
	Before all Cuts	0.732	0.240	0.124
Cut 1'	$E_T^{jet1,jet2} > 150$ GeV	0.063	0.039	0.065
Cut 2'	$E_T > 200$ GeV	0.084	0.110	0.197
Cut 3'	$M_{eff} > 1000$ GeV	0.437	0.471	0.350
Cut 4'	Transverse sphericity > 0.2	0.414	0.541	0.428
	$\sigma \times \epsilon_4$ (fb)	2.03	0.75	0.69

The c.s. of $0l$, $1l$ and $1\tau + X$ events for $m_{H^\pm} = 300$ GeV.

Outlook

- SUSY \tilde{g}/\tilde{q} events may appear as a serious background for charged Higgs search.
- Requires special cuts to minimise the SUSY backgrounds to have unambiguous signal.
- AT the early phase of LHC(14 TeV) running, possible to discover BSM physics(SUSY+Charged Higgs)
- It is very unlikely that Charged Higgs signal may appear as a background for \tilde{g}/\tilde{q} events.