

Discovery Potential Of SUPERSYMMETRY at the LHC with 7TeV C.O.M ENERGY

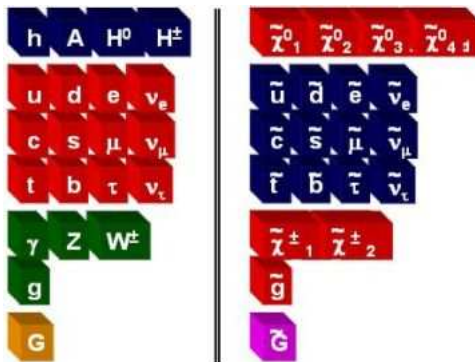
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- Standard Model is Successful in explaining low energy physics.
- Need to Find a Beyond Standard Model Candidate to extend the model to address various problems. (SM fine tuning, Dark matter, Unification)
- Supersymmetry has emerged as a robust candidate for a BSM.
- The Large Hadron collider is currently running at 7 TeV with low luminosity and is expected to achieve $1fb^{-1}$ by the end of 2011.
- One of the primary goal is to find BSM Physics.
- Analysis Of Susy signals has been done at 14TeV.
- Probe Susy Signal and signature at 7TeV.
- Work has been done previously by Baer-et.al,(arxiv: hep/ph-1004.3594v2),Prannath et-al(arxiv:hep/ph 1008.3423v1).
- We revisit the analysis in the leptonic channels, and $JET + \cancel{E}_T$ with a new set of cuts which are useful and leads to a better reach.
- Explore the possibility of SUSY signature with and without missing energy.

MSSM particle spectrum



Masses and Mixing Patterns of sparticles

- Supersymmetry is not an exact symmetry and is broken at some scale.
- Manifested as soft terms in the low energy.
- More than 100 parameters in unconstrained MSSM.
- After SUSY and EW breaking sparticles mix generically.
- The gauginos and the charge Higgs mix to give the chargino mass matrix

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- The gauginos and the charge Higgs mix to give the chargino mass matrix
- Mixing in the chargino sector:

$$\begin{pmatrix} \lambda^- & \tilde{h}_1^2 \end{pmatrix} \begin{pmatrix} M_2 & \sqrt{2}M_W \sin\beta \\ \sqrt{2}M_W \cos\beta & \mu \end{pmatrix} \begin{pmatrix} \lambda^+ \\ \tilde{h}_2^+ \end{pmatrix}$$

In terms of unitary matrices V,U chargino mass eigen states are given by

$$\chi_k^+ = V_{km} \psi_m^+$$

$$\chi_k^- = U_{km} \psi_m^-$$

with

$$U^* X V^{-1} = M_c^D$$

- This 2×2 mass matrix can be diagonalized by a biunitary transformation to get the mass eigen values which depend on $M_2, \mu, \tan \beta$

- The photino, bino and the neutral higgsinos mix to give mixing in neutralino sector
- \mathcal{M}^n given by

$$\begin{pmatrix} M_1 & 0 & -M_Z c_\beta s_W & M_Z s_\beta s_W \\ 0 & M_2 & M_Z c_\beta c_W & -M_Z s_\beta c_W \\ -M_Z c_\beta s_W & M_Z c_\beta c_W & 0 & -\mu \\ M_Z s_\beta s_W & -M_Z s_\beta c_W & \mu & 0 \end{pmatrix}$$

- Define two component neutralino mass eigen states by

$$\chi_i^0 = Z_{in} \psi_n^0$$

with $(\psi^0)^T = (\lambda_0 \quad \lambda_3 \quad \tilde{h}_1^1 \quad \tilde{h}_2^2)$ where Z is an unitary matrix defined as

$$Z^* \mathcal{M}^n Z^{-1} = \mathcal{M}_n^D$$

- Sparticle production modes at LHC:

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- Dominated by processes initiated by gluons and quarks at parton level.
-

$$pp \rightarrow \tilde{g}\tilde{g}, \tilde{q}\tilde{q} + \tilde{q}\tilde{q}^*, \tilde{g}\tilde{q},$$
$$\rightarrow \tilde{t}_i\tilde{t}_j, \tilde{b}_i\tilde{b}_j : i, j = 1, 2$$

for $m_{\tilde{g}} = m_{\tilde{q}} = 500\text{GeV}$ C.S $\sim 10\text{pb}$
for $m_{\tilde{g}} = m_{\tilde{q}} = 1000\text{GeV}$ C.S $\sim 70\text{fb}$

- If $m_{\tilde{g}} > m_{\tilde{q}}$

$$\tilde{g} \rightarrow \bar{q}\tilde{q}$$

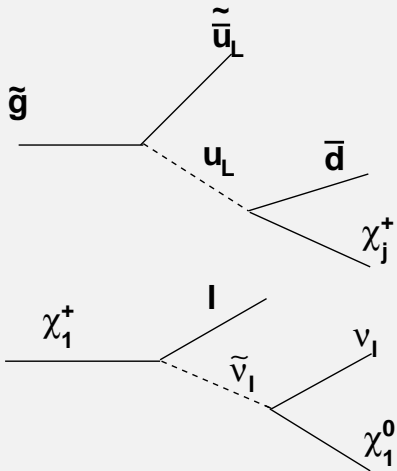
$$\begin{aligned} \tilde{q} &\rightarrow q'\chi_i^\pm \\ &\rightarrow q\chi_j^0 \quad i = 1, 2; j = 1 \dots 4 \end{aligned}$$

- If $m_{\tilde{g}} < m_{\tilde{q}}$

$$\begin{aligned} \tilde{g} &\rightarrow qq'\chi_i^\pm \text{ (55\%)} \\ &\rightarrow q\bar{q}\chi_j^0 \text{ (35\%)} \quad i = 1, 2; j = 1 \dots 4 \end{aligned}$$

$$\chi_i^\pm \rightarrow ff'\chi_i^0 \tag{1}$$

$$\chi_j^0 \rightarrow f''f'''\chi_1^0 \tag{2}$$





$$pp \rightarrow \tilde{g}\tilde{g}, \tilde{q}\tilde{q} + \tilde{q}\tilde{q}^*, \tilde{g}\tilde{q} \rightarrow m - leptons + n - jets + \cancel{p}_T$$

- Investigate 3 possible final states
- Single lepton(e, μ) + jets + \cancel{p}_T .
- dilepton +jets + \cancel{p}_T .
- Jets + \cancel{p}_T
- Work in the framework of msugra with 5 parameters $m_0, m_{1/2}, \tan \beta, A, \text{sgn}(\mu)$
- We look at certain benchmark points in the $m_0, m_{1/2}$ plane.
- We calculate the spectrum using [SUSYHIT](#) and [SUSPECT](#)

- SM Backgrounds include:

pp

- $t\bar{t} + jets (\sim 160 pb)$ (ALPGEN)
- $QCD (\sim 10^6 pb)$; (PYTHIA)
- $W + jets (\sim 10^4 pb)$; (ALPGEN)
- $Z + jets (\sim 10^3)$ (ALPGEN)
- $t\bar{t}W + jets (\sim 0.5 pb)$ (ALPGEN)
- $tbW (\sim 1.3)$ (ALPGEN)
- $WW, WZ, ZZ (\sim 45 pb)$ (PYTHIA)

- SUSY cross sections $\sim 2 pb$
- Jets are reconstructed using [FastJet](#) with [anti-kT algorithm](#).
- [CTEQ6L](#) as PDF from [LHAPDF](#) package.

- Set $\tan\beta = 45$, $A_0 = 0$ and $\text{sgn}(\mu) > 0$
- Choose the following benchmark points and scan the $m_0, m_{1/2}$ plane
- Satisfied by various constraints of MSSM.

	$m_0(\text{GeV})$	$m_{1/2}(\text{GeV})$	$m_{\tilde{g}}(\text{GeV})$	$m_{\tilde{q}}(\text{GeV})$	C.S(pb)
P_1	500	200	525	660	2.51
P_2	500	400	954	981	0.078
P_3	1500	200	575	1535	0.32
P_4	1500	250	690.2	1566	0.075
P_5	1000	200	553	1074	0.45
P_6	1000	300	776.2	1172	0.06

Table: The Benchmark points

	P_1	P_2	P_3	P_4	P_5	P_6
\tilde{g}	524.7	954	575	690.2	553	776.2
\tilde{u}_L	660	981	1535	1566	1074	1172.2
\tilde{u}_R	655	955	1533	1564	1071	1161.8
\tilde{e}_L	517.2	566	1498.6	1502	1004.6	1015.6
\tilde{e}_R	506.3	522.1	1499.3	1500	1001.6	1005.6
\tilde{t}_1	446.8	716.9	927.2	961.2	667.1	768.8
\tilde{b}_1	522.6	821.4	1098.6	1138.7	792.1	902.7
$\tilde{\tau}_1$	386.9	385.7	1185	1186.09	787.88	788.5
$\tilde{\chi}_1^0$	77.98	164.08	75.8	99.6	78.78	122.1
$\tilde{\chi}_2^0$	142.5	308.9	129.38	175.07	143.19	226.9
$\tilde{\chi}_1^+$ (NLSP)	141.95	308.8	126.05	173.5	142.36	226.5
$\tilde{\chi}_2^+$	296.3	514.6	240.8	293.4	284.4	386.9
h	109.4	114.02	114.6	114.8	111.9	113.45

Table: Sparticle Masses(GeV)

Sparticle	Decay mode	BR(%)
\tilde{g}	$q\bar{q}\chi_1^0, q\bar{q}\chi_2^0$	9.9, 30
\tilde{g}	$\chi_1^+ q\bar{q}'$	34
\tilde{g}	$\chi_2^+ q\bar{q}'$	13
χ_1^+	$\chi_1^0 q\bar{q}, \chi_1^0 l\bar{\nu}_l$	68,32
χ_2^+	$\chi_1^+ Z, \chi_1^0 W, \chi_1^+ h$	30,52,17
χ_2^0	$\chi_1^0 q\bar{q}$	76
χ_2^0	$\chi_1^0 ll$	4

Table: Branching ratio for Sparticles

- Single(di) lepton(e, μ) selected with 20(10)GeV +isolated

CUT DESCRIPTION

- Single(di) lepton(e, μ) selected with 20(10)GeV +isolated
- Jets selected with 50 GeV cut within $\eta \leq 3$
- single lepton $\rightarrow p_T^{j_1} > 250\text{GeV}$
- dilepton $\rightarrow p_T^{j_1} > 200\text{GeV}$
- Jet+ $\cancel{p}_T > \rightarrow p_T^{j_1} > 200\text{GeV}, p_T^{j_4} > 70\text{GeV}$

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- Cut on Transverse Thrust. $T_T < 0.9$

$$T_T = \max_{\vec{n}_T} \frac{\sum_i |\vec{p}_{T,i} \cdot \vec{n}_T|}{\sum_i |\vec{p}_{T,i}|}$$

For $T \simeq 1$ dijet events

For $T \simeq 1/2$ multijet events.

SUSY characterised by multijet events. close to 1/2.

- Single(di) lepton(e, μ) selected with 20(10)GeV +isolated
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For $T \simeq 1$ dijet events

For $T \simeq 1/2$ multijet events.

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- Cut on R3.

$$R3 = \frac{\sum_{i=1}^3 p_T^i}{H_T}$$

$$H_T = \sum_{i=1}^n p_T^i$$

$$R4 = \frac{\sum_{i=1}^4 p_T^i}{H_T}$$

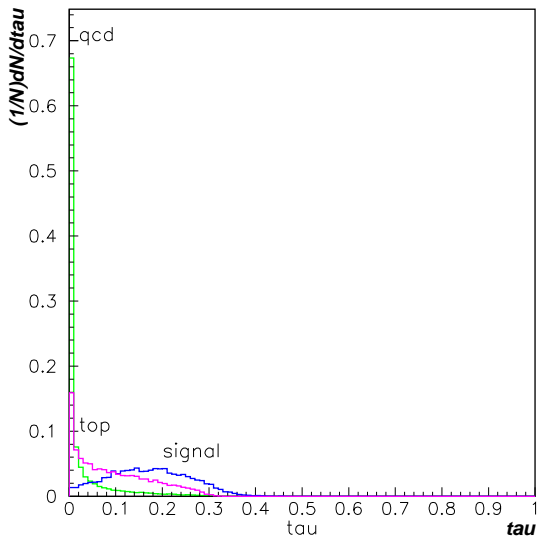
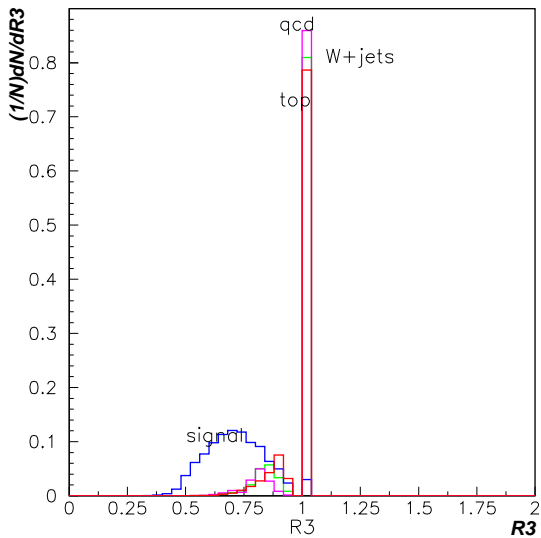


Figure: Distribution of $\tau = 1 - T$



- Cut on $m_T^{jj2} > 450$ for Jet+ \cancel{p}_T
designed to suppress dijet events coming from top or W.

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designed to suppress dijet events coming from top or W.
- Cut on the total sum of transverse momenta of jets
 $H_T = \sum_i p_T^i > 900$ GeV
- Missing energy cut: $\cancel{p}_T > 150$ GeV.
Calculated by taking a vector sum of Transverse momenta of all stable visible final state particles.
- Cut on transverse mass, $M_T > 60$ GeV.

$$M_T = \sqrt{2(p_T^l \times \cancel{p}_T(1 - \cos\phi))}$$

Event Summary for Single lepton

Proc	C.S(pb)	N	1lep	Thr	Jets	R3	H_T	$\sigma_0(\text{fb})$	m_T	\cancel{E}_T	$\sigma_{E_T}(\text{fb})$
$\tilde{g}\tilde{g}$	0.49	10K	2425	1853	627	553	335	15.5	203	115	5.5
$\tilde{g}\tilde{q}$	1.37	15k	3463	2656	1399	1225	865	80.26	553	341	32.4
$\tilde{q}\tilde{q}$	0.65	10k	2365	1770	1188	1019	861	56.6	518	382	24.8
$t\bar{t}(5-200)$	89.7	100K	19882	8435	111	31	11	9.86	4	0	0
$t\bar{t}(200-500)$	10.2	50K	12856	2708	245	99	38	7.75	20	3	.61
$t\bar{t}(500-\text{inf})$	0.1	20K	5379	336	293	123	87	0.4	35	16	.08
$t\bar{t} + 1 \text{ jet}$	34.8	13990	3457	1441	17	5	0	0	0	0	0
$t\bar{t} + 2 \text{ jet}$	13.5	4409	1252	589	29	14	1	.88	1	0	0
$t\bar{t} + 3 \text{ jet}$	3.96	2840	827	471	68	32	6	2.19	4	1	.37
W+1 jet	1308	640283	3592	1027	2	0	0	0	0	0	0
W+2jet	3302	77189	11211	3332	7	0	0	0	0	0	0
W+3jet	73	53119	17860	6054	102	4	0	0	0	0	0
W+4jet	14.8	17447	9198	3778	278	55	30	11	20	0	0
Z+1jet	139.	312652	1276	340	0	0	0	0	0	0	0
Z+2jet	36.4	112032	8217	2348	8	0	0	0	0	0	0
Z+3jet	8.1	40739	6722	2206	18	3	0	0	0	0	0
Z+4jet	1.6	13481	3320	1407	78	20	8	0.2	3	0	0
$t\bar{t}W$	0.065	12324	3777	1653	32	6	1	.005	1	0	0
$t\bar{t}W+1 \text{ jet}$	0.049	27968	8990	4605	299	133	26	.021	6	1	.00008
$t\bar{t}W+2 \text{ jet}$	0.0067	6687	2198	1250	204	121	54	.054	21	4	.004
tbW	1.3	43859	18410	7806	113	42	4	0.0091	2	0	0
QCD(200-300)	6868	7M	22284	2225	317	100	17	16.6	0	0	0
QCD(300-500)	837	1 M	3626	328	223	102	53	44.3	1	0	0
QCD(500-800)	40.3	1000K	438	27	26	8	8	3	1	0	0
QCD(800-1500)	1.55	50K	275	13	13	3	3	.09	0	0	0
QCD(1500 - inf)	0.003	50K	312	13	13	3	3	0	0	0	0

Table: Event summary for Single lepton case

Cross Section for processes

	P1	P2	P3	P4	P5	P6	BG
	$m_{\tilde{g}} = 525$ $m_{\tilde{q}} = 660$	$m_{\tilde{g}} = 954$ $m_{\tilde{q}} = 981$	$m_{\tilde{g}} = 575$ $m_{\tilde{q}} = 1535$	$m_{\tilde{g}} = 690.2$ $m_{\tilde{q}} = 1566$	$m_{\tilde{g}} = 553$ $m_{\tilde{q}} = 1074$	$m_{\tilde{g}} = 776.2$ $m_{\tilde{q}} = 1172$	
$\sigma_{0\dot{\rho}_T} (fb)$	152.3	6.97	15.2	7.61	41.74	9.052	96
$\sigma_{\dot{\rho}_T} (fb)$	62.7	5.13	6.86	2.62	16.8	5.88	1.05

Table: Cross Section for single lepton

	P1	P2	P3	P4	P5	P6	BG
	$m_{\tilde{g}} = 525$ $m_{\tilde{q}} = 660$	$m_{\tilde{g}} = 954$ $m_{\tilde{q}} = 981$	$m_{\tilde{g}} = 575$ $m_{\tilde{q}} = 1535$	$m_{\tilde{g}} = 690.2$ $m_{\tilde{q}} = 1566$	$m_{\tilde{g}} = 553$ $m_{\tilde{q}} = 1074$	$m_{\tilde{g}} = 776.2$ $m_{\tilde{q}} = 1172$	
$\sigma_{0\dot{\rho}_T} (fb)$	53.84	0.35	6.3	2.8	15.7	3.4	1.29
$\sigma_{\dot{\rho}_T} (fb)$	29.33	0.274	2.7	1.66	9.1	2.23	0.39

Table: Cross section for dilepton

	P1	P2	P3	P4	P5	P6	BG
	$m_{\tilde{g}} = 525$ $m_{\tilde{q}} = 660$	$m_{\tilde{g}} = 954$ $m_{\tilde{q}} = 981$	$m_{\tilde{g}} = 575$ $m_{\tilde{q}} = 1535$	$m_{\tilde{g}} = 690.2$ $m_{\tilde{q}} = 1566$	$m_{\tilde{g}} = 553$ $m_{\tilde{q}} = 1074$	$m_{\tilde{g}} = 776.2$ $m_{\tilde{q}} = 1172$	
$\sigma_{0\dot{\rho}_T} (fb)$	343	22.3	39.2	19.18	117.57	29	2559.03
$\sigma_{\dot{\rho}_T} (fb)$	216.75	20.5	25	13.2	71	19.34	3.19

Table: Cross section for Jet+Missing energy

Sensitivity Table at $1fb^{-1}$

	P1	P2	P3	P4	P5	P6
	$m_{\tilde{g}} = 525$ $m_{\tilde{q}} = 660$	$m_{\tilde{g}} = 954$ $m_{\tilde{q}} = 981$	$m_{\tilde{g}} = 575$ $m_{\tilde{q}} = 1535$	$m_{\tilde{g}} = 690.2$ $m_{\tilde{q}} = 1566$	$m_{\tilde{g}} = 553$ $m_{\tilde{q}} = 1074$	$m_{\tilde{g}} = 776.2$ $m_{\tilde{q}} = 1172$
$\frac{S}{\sqrt{B}}(\sigma_{0\beta_T})(fb)$	47.4	0.3	5.54	2.46	13.8	3
$S/\sqrt{B}(\sigma_{\beta_T})(fb)$	47	0.43	4.32	2.65	14.5	3.57

Table: Sensitivity for dilepton

	P1	P2	P3	P4	P5	P6
	$m_{\tilde{g}} = 525$ $m_{\tilde{q}} = 660$	$m_{\tilde{g}} = 954$ $m_{\tilde{q}} = 981$	$m_{\tilde{g}} = 575$ $m_{\tilde{q}} = 1535$	$m_{\tilde{g}} = 690.2$ $m_{\tilde{q}} = 1566$	$m_{\tilde{g}} = 553$ $m_{\tilde{q}} = 1074$	$m_{\tilde{g}} = 776.2$ $m_{\tilde{q}} = 1172$
$\frac{S}{\sqrt{B}}(\sigma_0)$	15.54	0.71	1.55	0.77	4.2	0.92
$\frac{S}{\sqrt{B}}(\sigma_{\beta_T})$	61	5.00	6.69	2.55	16.3	5.73

Table: Sensitivity for single lepton

	P1	P2	P3	P4	P5	P6
	$m_{\tilde{g}} = 525$ $m_{\tilde{q}} = 660$	$m_{\tilde{g}} = 954$ $m_{\tilde{q}} = 981$	$m_{\tilde{g}} = 575$ $m_{\tilde{q}} = 1535$	$m_{\tilde{g}} = 690.2$ $m_{\tilde{q}} = 1566$	$m_{\tilde{g}} = 553$ $m_{\tilde{q}} = 1074$	$m_{\tilde{g}} = 776.2$ $m_{\tilde{q}} = 1172$
$S/\sqrt{B}(\sigma_{0\beta_T})$	6.78	0.44	0.77	0.37	2.3	0.57
$S/\sqrt{B}(\sigma_{\beta_T})$	121.1	11.47	14	7.4	39.7	10.8

Table: Sensitivity for jet+missing energy

- We have studied detection possibility of SUSY in the LHC at 7 TeV C.O.M.
Single lepton+jets+ (\cancel{E}_T)
Dilepton jets+ (\cancel{E}_T) ,
Jets+ \cancel{E}_T .
- We designed some new cuts which suppressed the background without significantly affecting the signal.
- We find that with our cuts it is possible to discover SUSY signal at a mass range of $m_{\tilde{g}} = 1\text{TeV}, m_{\tilde{q}} = 1\text{TeV}$ at a 5σ level at 1fb^{-1} luminosity at 7TeV C.O.M energy.
- Our backgrounds are almost negligible, therefore this is a rate limited process.
- In single lepton channel our discovery reach goes upto 1 TeV in gluino mass which is better than previous analysis.
- In Jet+MET we get better sensitivity with our cuts.