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E_6SSM vs MSSM gluino phenomenology

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Abstract. The E_6SSM is a promising model based on the group E_6, assumed to be broken at the GUT scale, leading to the group $SU(3)\times SU(2)\times U(1)\times U(1)'$ at the TeV scale. It gives a solution to the MSSM μ-problem without introducing massless axions, gauge anomalies or cosmological domain walls. The model contains three families of complete 27s of E_6, giving a richer phenomenology than the MSSM. The E_6SSM generically predicts gluino cascade decay chains which are about 2 steps longer than the MSSM's due to the presence of several light neutralino states. This implies less missing (and more visible) transverse momentum in collider experiments and kinematical distributions such as M_{eff} are different. Scans of parameter space and MC analysis suggest that current SUSY search strategies and exclusion limits have to be reconsidered.

1 Introduction

Supersymmetry (SUSY) is a popular theory of physics beyond the Standard Model (SM) because by extending the Lorentz symmetry in the only possibly way you find

- A solution to the SM hierarchy problem,
- A dark matter (DM) candidate,
- An indication of a grand unification theory (GUT)
- A support for String Theory

The simplest, most studied model, the constrained version of the minimal supersymmetric standard model (MSSM), is already largely excluded. Both constraints from experiments and theoretical motivations, e.g. the μ-problem, forces us to look beyond the MSSM. To test more complicated SUSY models than the constrained MSSM or MSSM one needs to change current search strategies to make them flexible enough to be sensitive to extensions of the MSSM. The study presented here investigates the differences of gluino decays in MSSM and the E_6 inspired supersymmetric standard model (E_6SSM) [1].

2 E_6SSM

In the MSSM there is a bilinear Higgs coupling, μ, which needs to be of the order 1 TeV to give an acceptable electroweak symmetry breaking. Nothing prevents this SUSY preserving coupling to be of the order of the Planck scale. To naturally get a μ of order 1 TeV one may extend the MSSM with a scalar field S, which couples to the Higgs fields through an interaction $\lambda S H_u H_d$ and then let S get a VEV, $\langle S\rangle \equiv \frac{s}{\sqrt{2}}$. This provides a μ-term with $\mu = \frac{\lambda s}{\sqrt{2}}$. A consequence of this is that a global $U(1)$ Peccei-Quinn symmetry is introduced and broken. The breaking of this $U(1)$ implies the existence of a massless axion, which has not been observed. There are various proposed solutions to avoid the appearance of the axion:

- In the NMSSM a cubic term S^3 is added to break the global $U(1)$ to a descrete Z_3 symmetry. The breaking of this Z_3 could however lead to cosmological domain walls which would overclose the universe.
- In the USSM the $U(1)$ is gauged and a massive Z' boson appear instead but the theory is not anomaly free.
- In the E_6SSM the gauged $U(1)$ is a remnant of the breaking of a larger gauge group at the GUT scale - E_6. Anomalies are cancelled naturally since the particles lie in complete 27s of E_6.

The E_6 is broken down to the standard model with one extra surviving $U(1)$:

$$\begin{aligned} E_6 &\to SO(10)\times U(1)_\psi \\ &\to SU(5)\times U(1)_\chi \times U(1)_\psi \\ &\to SU(3)_C\times SU(2)_W\times U(1)_Y\times U(1)_N \end{aligned}$$

Each SM generation is contained in a 27 and it is the singlet, S, and the two Higgs doublets, H_u and H_d, of the third 27 that are assumed to acquire VEVs. The particle content is much bigger in the E_6SSM than in the MSSM or USSM because of these three 27s. Contained in these 27s there are, for example, right handed neutrinos, which are neutral under the extra U(1) and can thus be heavy and provide a see-saw mechanism. Furthermore, six more, naturally light, neutralino states are introduced in addition to the six neutralinos of the USSM. These neutralinos provide a new possible source of dark matter [2] and interesting Higgs [3] and gluino phenomenology[9].

3 Parameter spaces

The recent XENON100 experiment [4] puts a bound on the direct detection cross section for the LSP and WMAP [5] puts a bound on its relic density. These constraints excludes large portions of the parameter space for SUSY models. We have used CalcHEP [6] and MicrOMEGAs [7] when scanning the parameter spaces of MSSM and E_6SSM to pick out benchmarks which satisfy these constraints on the LSP as well as constraints from collider experiments.

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parameter	MSSM min	MSSM max	E_6SSM min	E_6SSM max	
$\tan\beta$	2	60	1.4	2	
$\lvert\lambda\rvert$	-	-	0.3	0.7	
s	-	-	2	5	[TeV]
μ	-2	2	-	-	
A	-3	3	-3	3	
M_A	0.1	2	1	3	

Table 1: To be able to compare the models on a common basis the gaugino masses were fixed so that a gluino mass of 800 GeV, a wino mass around 300 GeV and a bino mass around 150 GeV were provided. A common squark and slepton mass scale was fixed to $M_S = 2$ TeV. For the E_6SSM a large number of Yukawa couplings were scanned over which is omitted from this table.

The scanning regions are presented in Tab. 1 and points, including benchmarks, are plotted in the plane of the LSP relic density and the direct detection cross section in Fig. 2. The gluino decay chain length, l, relevant here is defined as the number of steps in the gluino decay chain after the first squark and illustrated in Fig. 1.

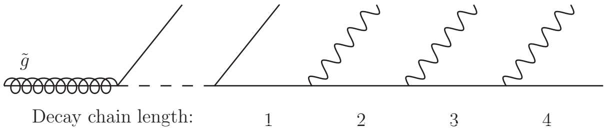

Fig. 1: The definition of the gluino decay chain length, l.

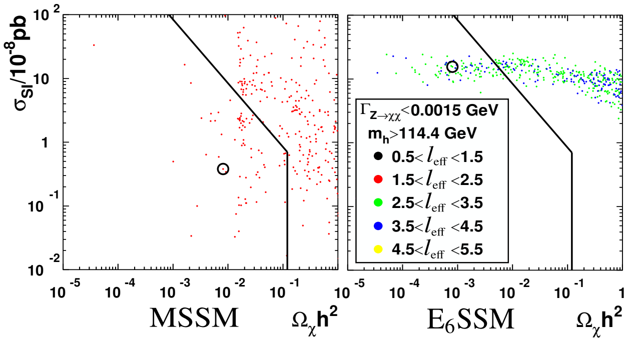

Fig. 2: The scanned regions of the parameter spaces projected onto the plane spanned by the spin independent cross section, σ_{SI}, and the relic density, Ωh^2. The area right of the solid line is excluded by XENON100 [4] and WMAP [5]. The colouring represents the effective gluino decay chain length $l_{\text{eff}} = \sum_l l \cdot P(l)$ for each point, where $P(l)$ is the probability for a chain length of l, as defined in Fig. 1. The chosen benchmarks of MSSM and E_6SSM are encircled.

4 Benchmarks

The benchmarks considered for MC event analysis are summarized in Tab. 2, where the neutralino spectrum is listed, and encircled in Fig. 2. These benchmarks do not provide a sufficient amount of dark matter and another source of dark matter is assumed. Other scenarios, where E_6SSM give the right amount of dark matter [8], have been considered in the same analysis [9], but are not presented here.

	MSSM	E_6SSM	
$\tan\beta$	39.2	1.77	
λ	-	-0.462	
s	-	5418	[GeV]
μ	1578	(-1770)	
A	-566.1	476.2	
M_A	302.5	2074	
M_1	150	150	
M_2	285	300	
$M_{1'}$	-	151	
$m_{\tilde{g}}$	800.2	800.0	
$P(l=1)$	0.188	$<10^{-5}$	
$P(l=2)$	0.812	0.1723	
$P(l=3)$	0	0.7986	
$P(l=4)$	0	0.02915	
$P(l=5)$	0	0	
Ωh^2	0.00816	0.0006937	
σ_{SI}	0.38×10^{-8}	16.35×10^{-8}	[pb]

	MSSM	E_6SSM	
$\tilde{\chi}^0_{M1}$	149.9	151.2	[GeV]
$\tilde{\chi}^0_{M2}$	302.8	303.7	
$\tilde{\chi}^0_{M3}$	1580	1766	
$\tilde{\chi}^0_{M4}$	1581	1771	
$\tilde{\chi}^\pm_{M1}$	302.8	300.9	
$\tilde{\chi}^\pm_{M2}$	1582	1771	
$\tilde{\chi}^0_{U1}$	-	1909	[GeV]
$\tilde{\chi}^0_{U2}$	-	2062	
$\tilde{\chi}^0_{E1}$	-	45.2	[GeV]
$\tilde{\chi}^0_{E2}$	-	53.2	
$\tilde{\chi}^0_{E3}$	-	141.6	
$\tilde{\chi}^0_{E4}$	-	187.4	
$\tilde{\chi}^0_{E5}$	-	227.8	
$\tilde{\chi}^0_{E6}$	-	265.6	
$\tilde{\chi}^\pm_{E1}$	-	122.7	
$\tilde{\chi}^\pm_{E2}$	-	225.1	
h	119.0	116.3	[GeV]
$\tilde{t}_1$	1992	2042	

Table 2: Properties of two chosen benchmarks. In the notation for neutralino and chargino states the subscript M denotes a MSSM-like state, U a USSM-like state and E an E_6SSM-like state. This distinction is reasonable since these sectors are very weakly coupled. The following number orders the states by mass.

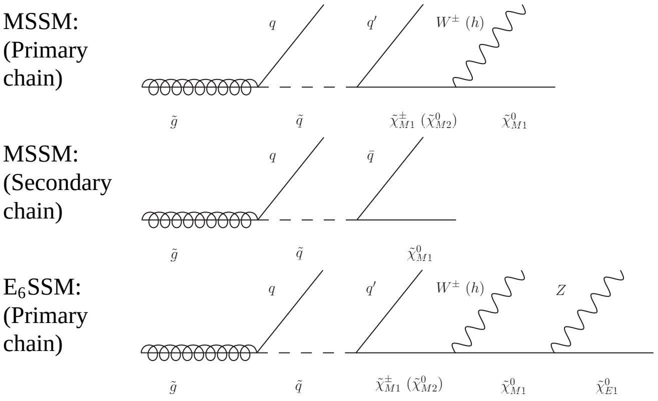

Fig. 3: Feynman diagrams for the leading gluino decay chains for each benchmark.

5 Event analysis

Since the E_6SSM introduces new neutralinos, naturally lighter than the MSSM LSP, the gluino decay chains will be longer than the MSSM's in general. This is confirmed and illustrated by the parameter scans in Fig. 2 and benchmarks in Tab. 2. An effect of longer decay chains is that there will be less missing momenta in collider experiments. This affects the conventional SUSY jets plus missing energy searches, e.g. [10], where the E_6SSM is disfavoured compared to the MSSM. This can be seen in Tab. 3 and Figs. 6 and 7. Another important feature is the increase in lepton as well as jet multiplicity, as shown in Fig. 4. Effective variables for distinguishing models with different gluino decay chain lengths, like the MSSM and the E_6SSM, are $\not{p}_T$ and $\not{p}_T/M_{\text{eff}}$, which are plotted in Fig. 5, where the smaller $\not{p}_T$ and larger M_{eff} of E_6SSM push these distributions to lower values.

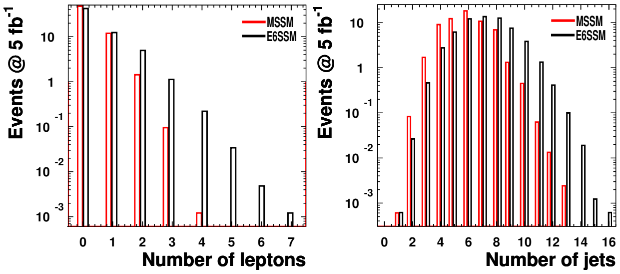

Fig. 4: Lepton multiplicity, requiring $p_T > 10$ GeV and $|\eta| < 2.5$, and jet multiplicity, requiring $p_T > 20$ GeV and $|\eta| < 4.5$.

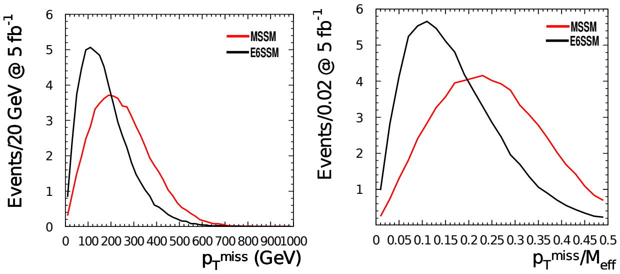

Fig. 5: Missing transverse momentum and its ratio with the effective mass, $M_{\rm eff}$, before selection cuts.

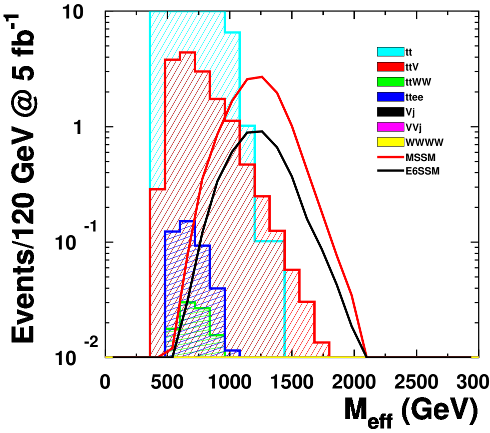

Fig. 6: The effective mass after 7 ATLAS style cuts

6 Conclusions

Careful analysis has to be made to distinguish SUSY models. The models studied here are very different but conventional cuts and the use of effective mass makes them blend into each other. The E_6SSM has large visible and small missing p_T. The effect of these features cancels in $M_{\rm eff}$, while it is enhanced in $\not{p}_T/\sum_{\rm visible}|p_T^{\rm visible}|$. Hard cuts on $\not{p}_T$ and $\not{p}_T/M_{\rm eff}$ or equivalents, like those used by ATLAS and CMS in Tab. 3, are severe for models with long decay chains. Large jet and lepton multiplicity searches should be the way forward for models like the E_6SSM.

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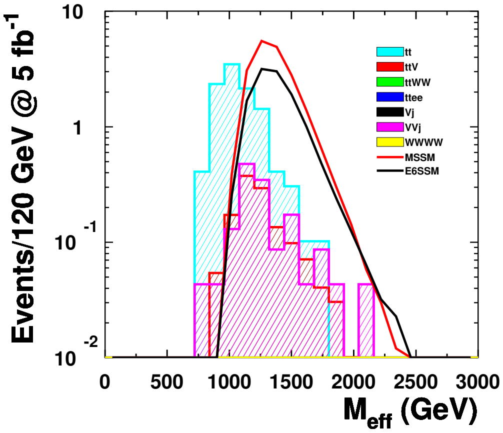

Fig. 7: The effective mass after 9 CMS style cuts

ATLAS CUTS No.	limit	MSSM Eff.	MSSM Frac.	E_6SSM Eff.	E_6SSM Frac.
0	no cut	0.00	1.00	0.00	1.00
1	$\not{p}_T$ >130 GeV	0.19	0.81	0.40	0.60
2	$p_T^{jet_1}$ >130 GeV	0.04	0.77	0.03	0.59
3	$p_T^{jet_2}$ >40 GeV	0.01	0.76	0.00	0.58
4	$p_T^{jet_3}$ >40 GeV	0.11	0.68	0.04	0.56
5	$p_T^{jet_4}$ >40 GeV	0.20	0.54	0.11	0.50
6	$\Delta\phi(\not{p}_T, jet)_{min} > 0.4$	0.37	0.34	0.58	0.21
7	$\not{p}_T/M_{\rm eff}$ >0.25	0.49	0.17	0.68	0.07

CMS CUTS No.	limit	MSSM Eff.	MSSM Frac.	E_6SSM Eff.	E_6SSM Frac.
0	no cut	0.00	1.00	0.00	1.00
1	$\not{H}_T > 200$ GeV	0.34	0.66	0.47	0.53
2	$p_T^{jet_1}$ >50 GeV	0.00	0.66	0.00	0.53
3	$p_T^{jet_2}$ >50 GeV	0.02	0.64	0.01	0.53
4	$p_T^{jet_3}$ >50 GeV	0.13	0.56	0.06	0.50
5	$\Delta\phi(\not{p}_T, jet_1) > 0.5$	0.02	0.55	0.03	0.48
6	$\Delta\phi(\not{p}_T, jet_2) > 0.5$	0.08	0.50	0.12	0.42
7	$\Delta\phi(\not{p}_T, jet_3) > 0.3$	0.07	0.47	0.10	0.38
8	$\Delta R(jet, lep)_{min} < 0.3$	0.24	0.36	0.36	0.25
9	$H_T > 800$ GeV	0.49	0.18	0.38	0.15

Table 3: Efficiency of ATLAS and CMS cuts and the fraction events left after successive applications of cuts.

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