

SUSY discovery potential of LHC14 with 0.3-3 ab^{-1} : A Snowmass whitepaper.

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We examine the discovery reach of LHC14 for supersymmetry for integrated luminosity ranging from 0.3 to 3 ab^{-1} . In models with gaugino mass unification and $M_1, M_2 \ll |\mu|$ (as for mSUGRA/CMSSM), we find a reach of LHC14 with 3 ab^{-1} for gluino pair production extends to $m_{\tilde{g}} \sim 2.3$ TeV while the reach via $\tilde{W}_1 \tilde{Z}_2 \rightarrow Wh + E_T^{\text{miss}}$ extends to $m_{\tilde{g}} \sim 2.6$ TeV.

Recently, the European Strategy for Particle Physics group has commissioned studies on the discovery potential of high luminosity options of LHC operating at $\sqrt{s} \simeq 14$ TeV[1]. Integrated luminosity values ranging from 0.3-3 ab^{-1} have been considered[2].

To assist this program, we presented computations in Ref. [3] of the high luminosity reach of LHC14 for discovery of supersymmetry within the context of the popular mSUGRA/CMSSM model (although our results should be valid more generally for most SUSY models with gaugino mass unification and $M_1, M_2 \ll |\mu|$). We examined the SUSY reach via the usually considered gluino and squark pair production reactions as well as from electroweak gaugino production. For very high integrated luminosities at the ab^{-1} range, the gaugino pair production reactions offers a larger reach opportunity since at very high mass values gluino and squark production becomes kinematically suppressed. We present our results here in an abbreviated summary form as a contribution to the US Snowmass Energy Frontier planning process.

We begin by considering the multi-jet + multi-lepton + E_T^{miss} signal that arises from gluino and squark pair production, followed by their cascade decays to charginos and neutralinos, with the decay chain terminating in a stable LSP that is the origin of E_T^{miss} . Following Ref. [3], we classify the events by lepton multiplicity, with additional requirements on jets:

- 0l: $n(l) = 0, n(j) \geq 3, \{E_T(j_1), E_T(j_2), E_T(j_3)\} > \{100 \text{ GeV}, 100 \text{ GeV}, 50 \text{ GeV}\}$;
- 1l: $n(l) = 1, n(j) \geq 2, \{E_T(j_1), E_T(j_2)\} > \{100 \text{ GeV}, 100 \text{ GeV}\}$;
- 2l: $n(l) = 2, n(j) \geq 2, \{E_T(j_1), E_T(j_2)\} > \{300 \text{ GeV}, 300 \text{ GeV}\}$.

We also evaluate dominant SM backgrounds to these topologies from $t\bar{t}$, W +jets, $Z \rightarrow \ell\ell$ +jets, $Z \rightarrow \nu\nu$ +jets and $Zt\bar{t}$ production. We deem the signal to be observable over the background after a $E_T^{\text{miss}} > E_T^{\text{miss}}(\text{min})$ cut if the number of signal events exceeds $\max [5 \text{ events}, 0.2N_B, 5\sqrt{N_B}]$ for a specified value of the integrated luminosity. Here N_B equals the corresponding number of background events. We optimize the signal relative to background by varying $E_T^{\text{miss}}(\text{min})$ between 100-1500 GeV in 100 GeV steps.

The LHC reach in each of these channels¹ is presented in Fig. 1 where we show the $m_0 - m_{1/2}$ plane for $\tan\beta = 10$ and $A_0 = -2m_0$. The large A_0 value is necessary to allow for large mixing in the top-squark sector, which is required to accommodate a Higgs mass $m_h \sim 125$ GeV. The solid (dashed) lines are for an integrated luminosity of 300 (3000) fb^{-1} .

For very large $m_{1/2}$, gluino and squark pair production cross-sections are suppressed in part by low PDF luminosities at large \hat{s} . In this case, the wino pair production reactions $pp \rightarrow \tilde{W}_1 \tilde{W}_1$ or $\tilde{Z}_2 \tilde{W}_1$ become

¹We have deliberately not shown results for the rate-limited low background same sign dilepton and trilepton channels because we were unable to reliably estimate the backgrounds for these very high integrated luminosity values. Also hard-to-estimate backgrounds from lepton fakes or charge misidentification could also make substantial contributions in these channels.

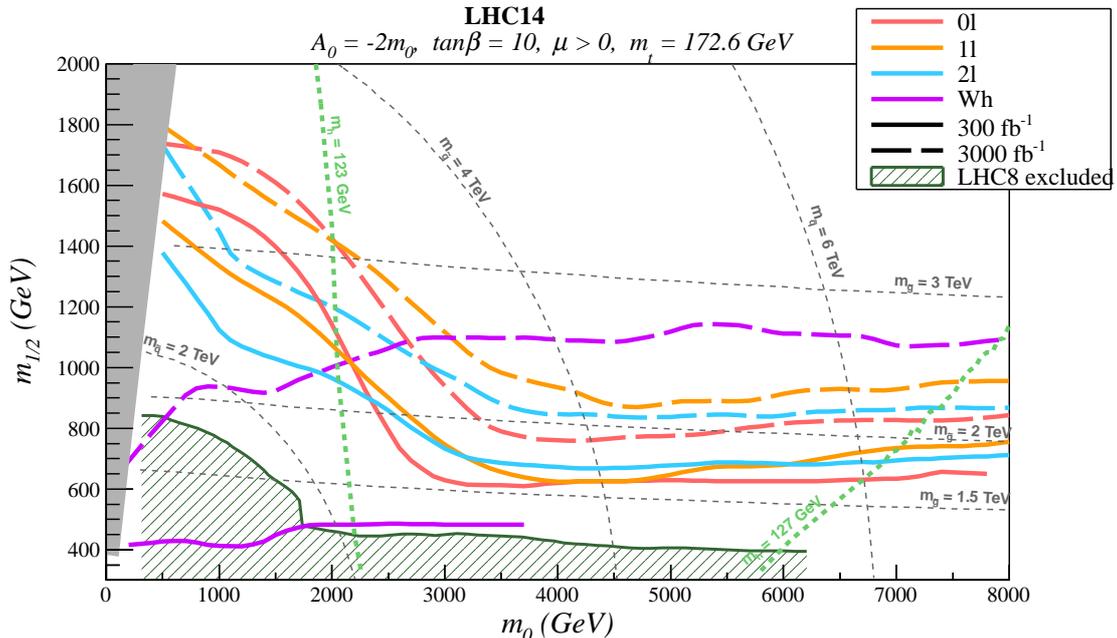


Figure 1: SUSY reach in the various channels discussed in the text for LHC14 for integrated luminosities of 300 fb^{-1} (solid lines) and 3000 fb^{-1} (dashed lines). The shaded grey area on the left side of the figure is excluded because the stau becomes the LSP. The green shaded region in lower-left and extending across the bottom is excluded by SUSY searches at LHC8 [4].

the dominant SUSY production processes, even more so in the case where squarks are also heavy[5], *i.e.* large m_0 . For the wino pair production reaction, the chargino typically decays via $\widetilde{W}_1 \rightarrow W\widetilde{Z}_1$ while the neutralino decays via $\widetilde{Z}_2 \rightarrow h\widetilde{Z}_1$ if $m_{\widetilde{Z}_2} - m_{\widetilde{Z}_1} > m_h$. The signals from chargino pair production are typically buried below SM backgrounds from WW , Wj and $t\bar{t}$ production. Following Ref. [6], we focus on the $\widetilde{W}_1\widetilde{Z}_2 \rightarrow Wh + E_T^{\text{miss}} \rightarrow \ell b\bar{b} + E_T^{\text{miss}}$ signal. To extract signal from various backgrounds, we require

- $n(\ell) = 1$, $n(b) = n(j) = 2$, $\Delta\phi(b, b) < \pi/2$, $M_{eff} > 350 \text{ GeV}$, $m_T(\ell, E_T^{\text{miss}}) > 125 \text{ GeV}$, $100 \text{ GeV} < m_{bb} < 130 \text{ GeV}$.

Here $M_{eff} = \sum_i E_T(j_i) + \sum_i p_T(l_i) + E_T^{\text{miss}}$, $m_T(\ell, E_T^{\text{miss}})$ is the transverse mass and m_{bb} the invariant mass of the b-jet pair. As before, we optimize with respect to $E_T^{\text{miss}}(\text{min})$. The reach via this Wh channel is shown by the purple curves in Fig. 1. We see that while the strong production dominates the LHC reach for 300 fb^{-1} , the reach via the Wh channel exceeds that from gluino production (if squarks are heavy) for an integrated luminosity of 3 ab^{-1} .

Our results for the reach, expressed in terms of $m_{\widetilde{g}}$, are summarized in Table 1. Although we have illustrated the results using the mSUGRA/CMSSM framework, we expect that the qualitative features of the Table will be valid in any model with gaugino mass unification and large $|\mu|$. In contrast, in models where $|\mu| \ll |M_{1,2}|$, then wino pair production leads to a striking hadronically-quiet same-sign diboson signal with $\ell^\pm\ell^\pm + E_T^{\text{miss}}$ final state that again yields a larger reach than gluino and squark pair production for integrated luminosities greater than 300 fb^{-1} [7].

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\mathbb{L} (fb^{-1})	$m_{\tilde{q}} \sim m_{\tilde{g}}$	$m_{\tilde{q}} \gg m_{\tilde{g}}$	Wh
100	3.0 TeV	1.6 TeV	- TeV
300	3.2 TeV	1.8 TeV	1.2 TeV
1000	3.4 TeV	2.0 TeV	2.0 TeV
3000	3.6 TeV	2.3 TeV	2.6 TeV

Table 1: Optimized SUSY reach of LHC14 within the mSUGRA/CMSSM model expressed in terms of $m_{\tilde{g}}$ for various choices of integrated luminosity. The $m_{\tilde{q}} \sim m_{\tilde{g}}$ and $m_{\tilde{q}} \gg m_{\tilde{g}}$ values correspond to the maximum reach in the $0l$, $1l$ and $2l$ channels from gluino and squark pair production while the Wh values shown correspond to the reach in the Wh channel for $m_{\tilde{q}} \gg m_{\tilde{g}}$.

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