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 + $E_T^{\text{miss}}$ 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 $E_T^{\text{miss}}$. Following Ref. [2], 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 $\max \left[ 5 \text{ events}, 0.2N_B, 5\sqrt{N_B} \right]$ 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 channels 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
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 [3], i.e. large $m_0$. For the wino pair production reaction, the chargino typically decays via $\tilde{W}_1 \rightarrow W \tilde{Z}_1$ while the neutralino decays via $\tilde{Z}_2 \rightarrow h \tilde{Z}_1$ if $m_{\tilde{Z}_2} - m_{\tilde{Z}_1} > m_h$. The signals from chargino pair production are typically buried below SM backgrounds from $W W$, $W j$ and $t \bar{t}$ production. Following Ref. [4], we focus on the $W_1 \tilde{Z}_2 \rightarrow Wh + E_T^{miss} \rightarrow \ell b + E_T^{miss}$ signal. To extract signal from various backgrounds, we require

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

Here $M_{eff} = \sum_i E_T(j_i) + \sum_i p_T(l_i) + E_T^{miss}$, $m_T(\ell, E_T^{miss})$ is the transverse mass and $m_{bb}$ the invariant mass of the b-jet pair. As before, we optimize with respect to $E_T^{miss}(min)$. 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$^{-1}$ [7].

Our results for the reach, expressed in terms of $m_{\tilde{g}}$, 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 $\ell^+\ell^+$ 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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\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
IL (fb\(^{-1}\)) & \(m_{\tilde{q}} \sim m_{\tilde{g}}\) & \(m_{\tilde{q}} \gg m_{\tilde{g}}\) & \(W h\) \\
\hline
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 \\
\hline
\end{tabular}
\caption{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 0\(l\), 1\(l\) and 2\(l\) channels from gluino and squark pair production while the \(W h\) values shown correspond to the reach in the \(W h\) channel for \(m_{\tilde{q}} \gg m_{\tilde{g}}\).}
\end{table}

References


