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. Integrated luminosity values ranging from 0.3-3 ab$^{-1}$ have been considered.

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 $\max[5 \text{ events}, 0.2N_B, 5\sqrt{N_B}]$ 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 channels is presented in Fig. 1, where we show the $m_{\tilde{t}} - m_{\tilde{t}1/2}$ 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 $m_{\tilde{t}1/2}$, 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 [5], 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 $WW$, $Wj$ and $t\bar{t}$ production. Following Ref. [6], we focus on the $\tilde{W}_1 \tilde{Z}_2 \rightarrow Wh + E_T^{\text{miss}} \rightarrow \ell b + E_T^{\text{miss}}$ 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, $m_T(\ell, E_T^{\text{miss}}) > 125$ GeV, 100 GeV < $m_{bb}$ < 130 GeV.

Here $M_{eff} = \sum_i E_T(j_i) + \sum_i p_T(l_i) + E_T^{\text{miss}}$, $m_T(\ell, E_T^{\text{miss}})$ 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 $m_{\tilde{g}}$, 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 $\ell^{\pm} \ell^{\pm} + E_T^{\text{miss}}$ 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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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 $m_{\tilde{g}} \sim m_{\tilde{g}}$ and $m_{\tilde{g}} \gg m_{\tilde{g}}$ values correspond to the maximum reach in the 0l, 1l and 2l channels from gluino and squark pair production while the $W h$ values shown correspond to the reach in the $W h$ channel for $m_{\tilde{q}} \gg m_{\tilde{g}}$.

| IL (fb$^{-1}$) | $m_{\tilde{g}} \sim m_{\tilde{g}}$ | $m_{\tilde{g}} \gg m_{\tilde{g}}$ | $W h$  |
|----------------|----------------------------------|----------------------------------|--------|
| 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|

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