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Current bounds and future prospects of light neutralino dark matter in NMSSM

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We examine the region of the parameter space of the Next to Minimal Supersymmetric Standard Model (NMSSM) with a light neutralino~($M_{\tilde{\chi}_1^0} \leq$ 62.5 GeV) where the SM-like Higgs boson can decay invisibly, the thermal neutralino relic density is smaller than the measured cold dark matter relic density, and where experimental constraints from LHC searches and flavor physics are satisfied. We observe allowed regions of parameter space where the lightest neutralino could have a mass as small as $\leq$ 10 GeV while still providing a significant component of relic dark matter (DM). We then examine the prospects for probing the NMSSM with a light neutralino via direct DM detection searches, via invisible Higgs boson width experiments at future e^+e^- colliders, via searches for a light singlet Higgs boson in $2b2\mu$, $2b2\tau$ and $2\mu2\tau$ channels and via pair production of winos or doublet higgsinos at the high luminosity LHC and its proposed energy upgrade. For this last-mentioned electroweakino search, we perform a detailed analysis to map out the projected reach in the $3l + \not{E}_{\rm T}$ channel, assuming that chargino decays to $W\tilde{\chi}_1^0$ and the neutralino(s) decay to Z or H_{125} + $\tilde{\chi}_1^0$. We find that the HL-LHC can discover SUSY in just part of the parameter space in each of these channels, which together can probe almost the entire parameter space. The HE-LHC probes essentially the entire region with higgsinos~(winos) lighter than 1~TeV~(2~TeV) independently of how the neutralinos decay, and leads to significantly larger signal rates that may allow further exploration of the underlying new physics.

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