An upgrade study of chargino detection with finer mass splittings.

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I. INTRODUCTION

In the Standard Model (SM) Higgs mass is highly sensitive to the details of the physics at high-energy [1]. Unless we accept big number cancellations, SM does not work well with naturalness principle which leads us to beyond SM (BSM) physics. This issue is resolved in supersimmetry (SUSY) introducing new particles, new processes at higher energies [2]. With a present data from large hardron collider (LHC) [3] we know that all SUSY particles should be heavy except higgsino, where lower bound is established from LEP[1] 100 GeV. On the other hand for naturalness principle to hold higgsino mass has upper bound of about 1 TeV. Here we consider possibility to push lower bound of higgsino mass with high luminosity LHC data from ATLAS experiment [4, 5], therefore we initially consider higgsino mass to be $m_h = 100$ GeV and its mass splittings $\Delta m_h = 5$ GeV (see fig. 1).

Similarly as in previous studies [6] here we are considering chargino, neutralino $\tilde{\chi}_1^+$, $\tilde{\chi}_1^-$ production which decays to neutralinos, neutrinos and soft leptons (see fig. 1). These leptons are buried in SM background coming mainly from $pp \to \tau\tau + j$, $pp \to t\bar{t} + j$, $pp \to WW + j$ as thy have comparable cross-section as a signal (see table I). Also in our analysis we include process $pp \to W + j$ which although produces one soft lepton it has a large cross-section and therefore considerable chance for incorrectly detecting second lepton coming from jet (fake leptons).

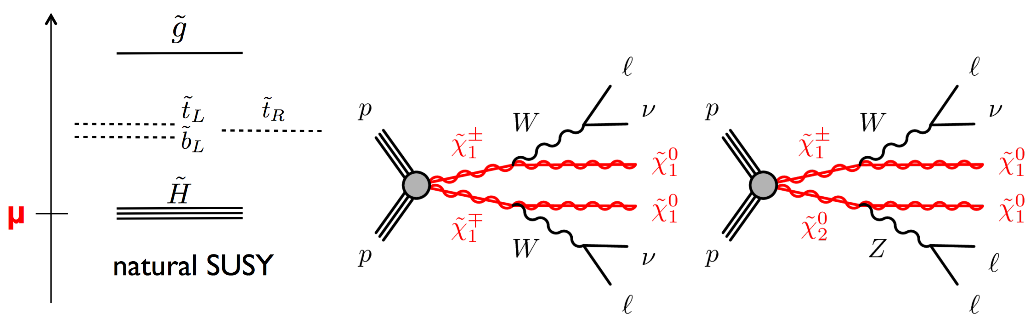

FIG. 1: The SUSY particle mass spectrum with higgsino mass μ (left), 2 soft lepton SUSY signal (middle) and 3 soft lepton SUSY signal (right).

Process	σ_{eff}
$pp \to \tau\tau + j$	47.6 pb
$pp \to t\bar{t} + j$	8.9 pb
$pp \to W + j$	162 pb
$pp \to WW + j$	1.34 pb
$pp \to \tilde{\chi}_1^+ \tilde{\chi}_1^- + j \to WW + j$	2.8 pb
$pp \to \tilde{\chi}_1^+ \tilde{\chi}_2^0 + j \to WZ + j$	5 pb

TABLE I: Cross sections at 14 TeV for the signal and background processes considered.

To study and compare the signal and backgrounds, we turn to Monte Carlo. We simulate the hard processes for the signal and the major backgrounds with Madgraph 6. The parton-level events are then showered and hadronized with Pythia 8.

[1] Large electron positron accelerator.

II. SIMPLIFIED DETECTOR SIMULATION

Each simulated event consists of number of objects - particles, particle showers coming from quark hardronization (jets) and missing energy E_T^{miss} which we know from transverse momenta conservation. For each of these objects simulation gives us Lorentz four-vector and so we can calculate - energy, mass, momenta, transverse angle ϕ[2], pseidorapidity η.[3] as well as object labels - electron, positron, muon, lepton, jet, b-jet, photon. Unfortunately event reconstruction is limited by a detector imperfections, geometry, resolution and other properties. Because a real detector simulation is costly here we are going to use simplified model.

Firstly we smear object energies, masses, momenta, η, ϕ, jet labels[4] of all objects (particles and jets) with corresponding performance functions for 200 average interactions per bunch crossing as expected in HL LHC. Then from these smeared event particles we are able to detect only ones which hit detector $|\eta| < 2.8$ and are energetic enough to trigger detector - for leptons $p_{\mathrm{T}} > 5$ GeV and for jets $p_{\mathrm{T}} > 50$ GeV.

Because we are not interested in particles which comes from quark hardronization (jets) then we have to exclude particles which comes from jets. At overlap removal stage if lepton and jet are separated with less than $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} < 0.2$ and if transverse momenta of lepton is at least 50 % of transverse momenta of jet then we discard jet. For remaining objects if distance between jet and lepton is $\Delta R < 0.4$ we discard lepton assuming it belongs to the jet. We also assume that lepton belongs to jet if it has small energy and momenta compared to all particles around the cone. And eventually because we are not considering resonance processes at low energies we are removing low mass lepton pairs which have energy less than 12 GeV.

For checking this simplified detector simulation we plot transverse momentum of leading jet and leading lepton at different stages of algorithm (see figure fig. 2). For jets we see that smearing of variables indeed makes distribution broader (red line) where cut at 30 GeV corresponds to undefined behavior of smearing function. Then some jets are removed at overlap removal stage while majority are discarded with p_{T} threshold (green line). Similarly for leading lepton we see considerable smearing (red line) and discarded leptons with p_{T} threshold and a little amount discarded at overlap removal stage (green line).

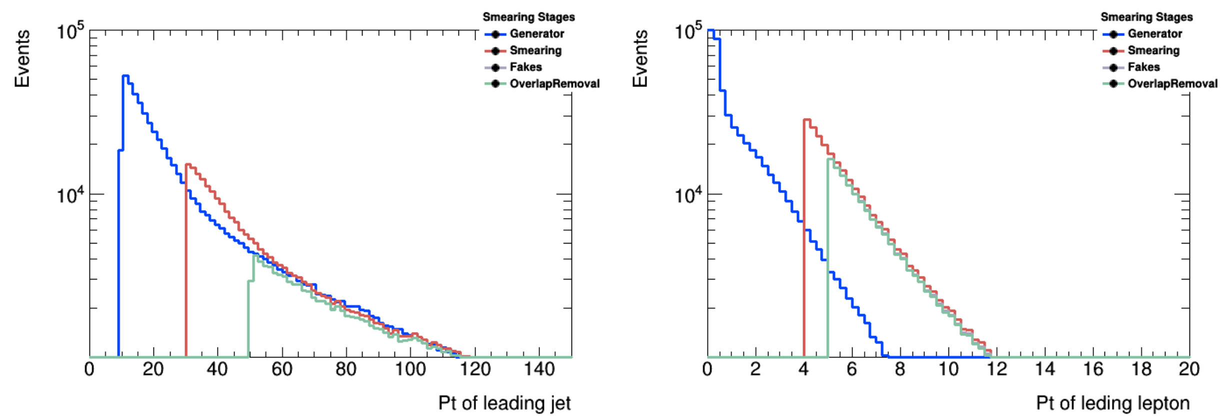

FIG. 2: Tests of smearing functions for signal sample C1C1 at different stages for leading jet p_{T} (left) and leading lepton p_{T} (right). Generator (blue line), smearing stage (red line) and overlap removal (green line).

III. EVENT SELECTION

Without any selection we have low signal and background relative ratio as in fig. 3 which also helps us to check the simulation. For example we see resonance for transverse mass at 90 GeV for $pp \to W + j$ as expected. To increase signal ratio over background we are going to apply selection.

[2] Because of symmetry, we are only concerned with angle differences between objects.
[3] Commonly used spatial coordinate describing angle of particle relative to beam axis. It is related to angle between momentum and beam axis with formula $\theta = 2\arctan(e^{-\eta})$.
[4] Because of efficiency with which we can distinguish jets from b-jets.

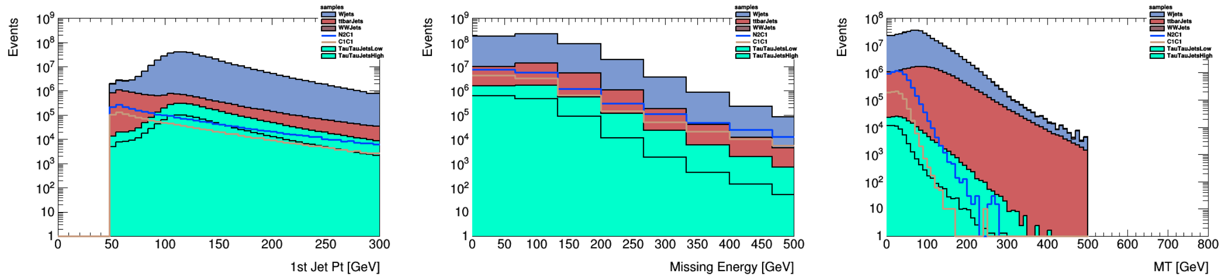

FIG. 3: Missing energy (left), two leading lepton mass m_{ll} (middle) and transverse mass (right). SUSY signals (blue and orange lines), background processes (filled green, red, blue).

The signal (see fig. 1) produces soft leptons (small transverse momenta) as well as some jets and neutrinos, neutralinos. The latter ones does not leave trace in ATLAS detector and so violates detected transverse momenta conservation which we measure with missing energy.

When both neutralinos are forced to recoil against another object in the event - a jet in this case here - they lead to a large $E_T^{\rm miss}$ signature. In order to have such forced events we require single energetic jet which points backwards from missing energy as well we need large missing energy. Therefore the first requirements we impose

- Single jet with $p_{\rm T} > 100$ GeV;
- $E_T^{\rm miss} > 200$ GeV;
- $\Delta\Phi(E_T^{\rm miss}, 1st\ jet) > 0.4$;

The requirement of single energetic jet also kills majority of $pp \to t\bar{t} + j$ background which is characterized by at least two hard jets. If we even more assume that event is b-tagged we can minimize this background without affecting the signal. Here we assume a b-tag efficiency of 80% which we apply at smearing stage.

Majority of background $pp \to W + j$ and $pp \to \tau\tau + j$ are killed if we apply veto for at least two leptons in the process[5]. On the other hand background $pp \to WW + j$ did not survive previous selection therefore for minimizing background overall we apply selections

- No b-tagged jets;
- At least 2 leptons[6].

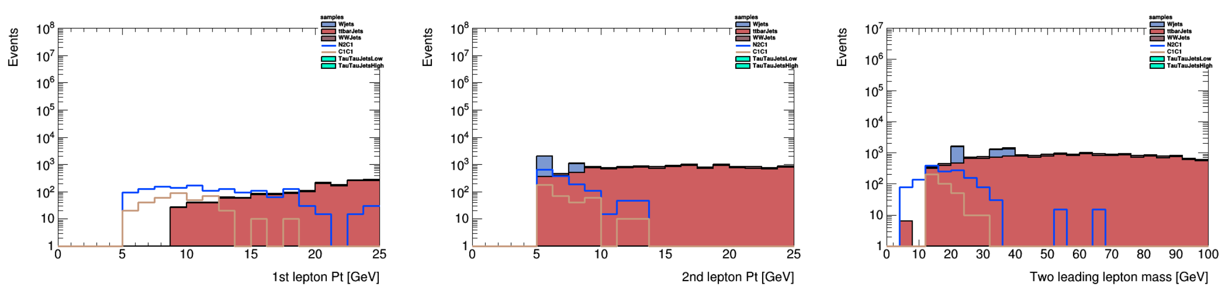

FIG. 4: The signal after selection. Leading lepton $p_{\rm T}$ (left), second leading lepton $p_{\rm T}$ (middle), first two leading lepton mass. SUSY signals (blue and orange lines), background processes (filled green, red, blue).

The results of this selection can be seen in in fig. 4. The signal over background ratio indeed has improved and has enough events at $L = 3000{\rm fb}^{-1}$ showing efficiency of present selection. Selecting events for leading lepton transverse momenta in range $5 < p_{\rm T} < 20$ GeV we calculate exact significance at table II.

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[5] Although it would not be so easy for $pp \to W + j$ in real life since in this study we lack to add lepton fakes for each event.
[6] Because of simplified detector algorithm lepton energies are larger than 5 GeV (look in ApplyPtEtaThresholds).

Process	$\text{Events}_{\text{L}=3000\ \text{fb}^{-1}}$	$\sigma_{L=300\ \text{fb}^{-1}}$	$\sigma_{L=3000\ \text{fb}^{-1}}$
$\tau\tau$	0	-	-
$t\bar{t}$	758 ± 27	-	-
WW	67 ± 8	-	-
W	0	-	-
TOTAL	825 ± 35	-	-
$\chi_1^{\pm}\chi_1^{\pm}$	370 ± 19	0	0
$\chi_1^{\pm}\chi_2^{0}$	1422 ± 38	0	0

TABLE II: Significance calculation for leading lepton p_{T} in region $5 < p_{\text{T}} < 20$ GeV luminosity $L = 300\ \text{fb}^{-1}$ and $L = 3000\ \text{fb}^{-1}$ with background uncertainty 30 %.

IV. CONCLUSIONS

In this study we have shown usefulness of HL LHC data for pushing bounds of higgsino masses previously set by LEP targeting soft leptons possibly coming from chargino and neutralino production by applying reasonable event selections. We have shown that single energetic jet which points backwards from large missing energy is indeed efficient selection and could be used as basis for more detailed studies. After adding veto for no b-jets and requiring at least 2 leptons we found that most significant contribution for background comes from $pp \to t\bar{t} + j$ where better understanding on how it can be minimized is needed.

With this selection we found that signal emerges most boldly for leading lepton transverse momenta which we used for significance calculation. With $L = 3000\ \text{fb}^{-1}$ and background uncertainty 30% we found significance to be ... for $\chi_1^{\pm}\chi_1^{\pm}$ and ... for $\chi_1^{\pm}\chi_2^{0}$ which can (can't) be used as a tool for pushing lower bound of higgsino mass. However validness of this result can be greatly altered since our simplified detector simulation does not consider lepton fakes comming from large $pp \to W + j$ background.

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