An upgrade study of chargino detection with finer mass splittings.

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(Dated: August 2016)

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 initialy consider higgsino mass to be $m_h = 100$ GeV and its mass splittings $\Delta m_h = 5$ GeV (see fig. 1).

Similarly as in previos 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 comming 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 incorectly detecting second lepton coming from jet (fake leptons).

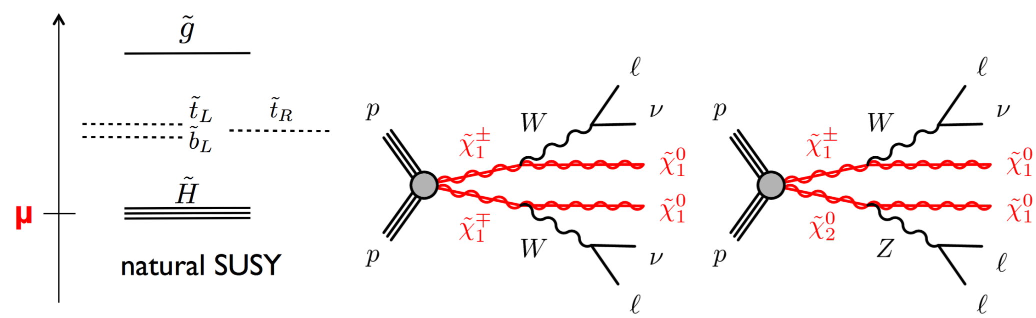

FIG. 1: The SUSY particle mass specturm with higgsino mass μ (left), 2 soft lepton SUSY signal (middle) and 3 soft lepton SUSY signal (right).

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 consits of number of objects - particles, particle showers comming from quark hardronization (jets) and missing energy E_T^{miss} which we know from transverse momenta conservation. For each of theese 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. Unfortunatelly 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).

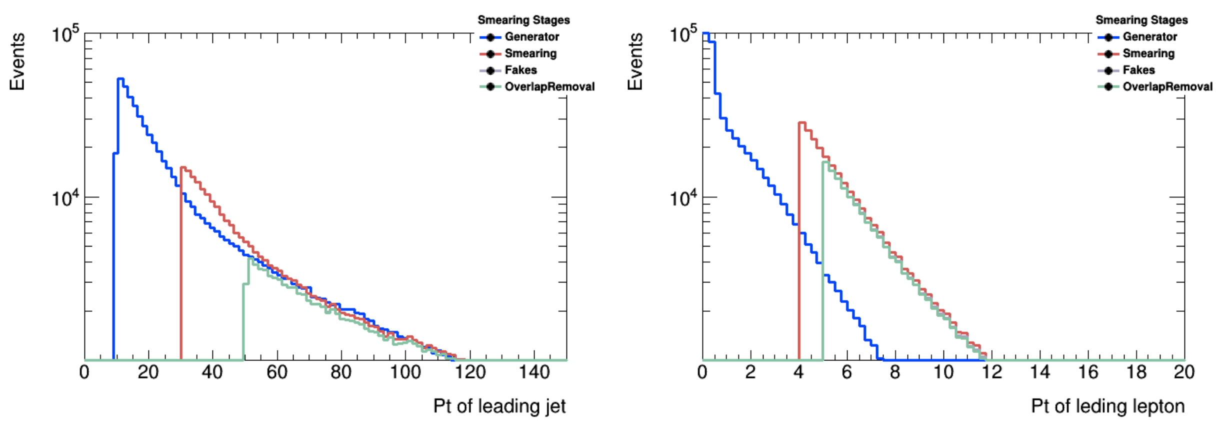

FIG. 2: Tests of smearing functions for signal sample C1C1 at different stages for leading jet p_{T} (left) and leading lepton p_{T} (right). Generator (blue line), smearing stage (red line) and overlap removal (green line).

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.

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[2] Because of symmetry, we are only concerned with angle differences between objects.
[3] Commonly used spatial coordinate describing angle of particle releative to beam axis. It is releated 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.

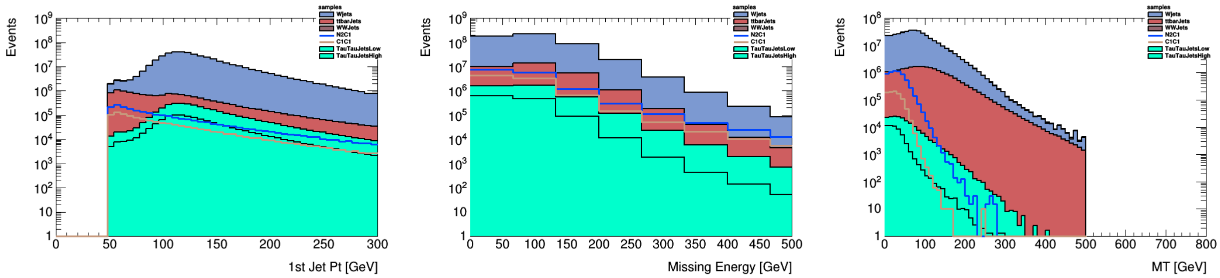

FIG. 3: Missing energy (left), two leading lepton mass m_{ll} (middle) and transverse mass (right). SUSY signals (blue and orange lines), background processes (filled green, red, blue).

We now that in the signal leptons are soft (small transverse momenta) and neitralinos, neitralinos does not leave trace to our detector which is indirectly detected as missing energy. If we consider single jet with large transverse momentum in our process then because of transverse momentum conservation in our signal we expect large missing energy. We also know that in signal process we don't have b-jets so we can eliminate with it background $pp \to t\bar{t} + j$. Therefore selection we are considering is

- $E_T^{\text{miss}} > 200$ GeV.
- Single Jet with $p_\text{T} > 100$ GeV and no b-jets in event.
- $\Delta\Phi(E_T^{\text{miss}}, 1st\ jet) > 0.4$
- At least 2 leptons because they are characteristic to our signal.[5]

which can be seen in fig. 4.

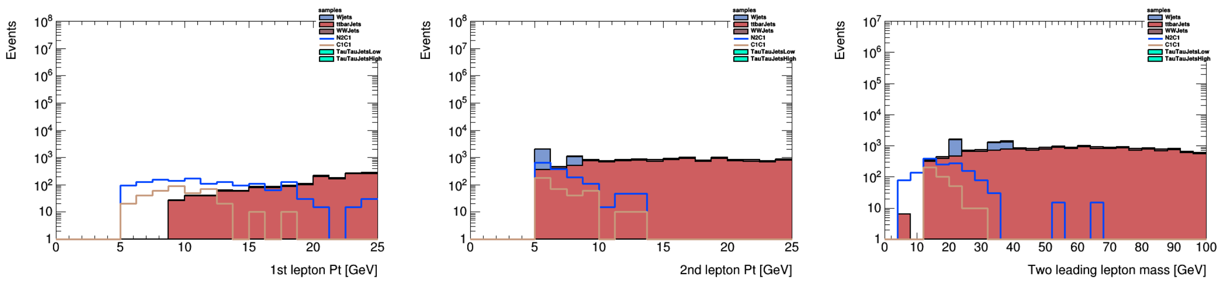

FIG. 4: The signal after selection. Leading lepton p_T (left), second leading lepton p_T (middle), first two leading lepton mass. SUSY signals (blue and orange lines), background processes (filled green, red, blue).

After this selection we see that indeed signal ratio is improved, but still a lot of background $pp \to t\bar{t} + j$ still is left which needs more carefull analysis on how it can be excluded. For significance calculation we use leading lepton transverse momentum in a region $5 < p_\text{T} < 20$ GeV where results can be seen in table II.

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

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

[5] Because of simplified detector algorithm lepton energies are larger than 5 GeV (look in ApplyPtEtaThresholds).

IV. CONCLUSIONS

- With selection used in this report we are able to better distinguish signal from background processes.
- SM process $pp \to t\bar{t} + j$ is not excluded efficiently enough with a present selection. A further study of how it can be minimized is needed.
- The significance discovering higgsino particle with mass 100 GeV at HL LHC is ... which is (not) enough for making discovery.

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