Determination of the Neutralino Mass Difference between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ and its Relation to the mSUGRA Model Parameter $m_{1/2}$.

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ABSTRACT

The mass difference between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ is determined using the 3 body decay $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \ell^+ \ell^-$. The analysis technique is demonstrated for a set of parameters in the mSUGRA space, the LHC-NLC-TEVATRON comparison point. At this point neutralinos are copiously produced in gluino cascade decays, so the mass difference determination will be limitied by systematic errors and not statistics. The relation between the neutralino mass difference and the global mSUGRA model parameter $m_{1/2}$ is discussed.

I. INTRODUCTION

After a discovery of SUSY, the aim will be to measure all sparticle properties and test candidate SUSY models and determine their global parameters. Direct mass measurements are complicated since each SUSY event contains two lightest supersymmetric particles (denoted $\tilde{\chi}_1^0$). This particle is neutral and stable, therefore escaping detection. However mass differences between sparticles are easily measured in 3 body decays [1]. In this report the decay

$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \ell^+ \ell^-$$

is used to determine the neutralino mass difference, $\Delta M_{\tilde{\chi}^0} = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$. The leptonic decay of the $\tilde{\chi}_2^0$ has a significant branching fraction in a large part of the parameter space where the decay $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 h^0$ is not kinematically allowed. The invariant mass of the leptons has a sharp edge at the value of the neutralino mass difference. This neutralino mass difference is closely related to the global parameter $m_{1/2}$ in the "minimal supergravity–inspired model" (mSUGRA). In this report this SUSY process is studied in the mSUGRA point defined by the parameters given in table I (in LHC notation Point D, the so called comparison Point[1]). At this Point total SUSY production cross section is enormous – 1356 pb (1.3 million events per year per experiment!) The branching ratio BR($\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \ell^- \ell^+$) is 16% per lepton species. The large production rate of SUSY events give a very large signal over Standard Model background.

II. SIMULATION

SUSY events were generated using the Monte Carlo program ISAJET 7.20 [2]. The detector response was simulated with ATLFAST 1.03 [2] [4], a fast toy detector package tuned to simulate expected ATLAS performance. A b-tagging efficiency of 60 % and impurities of 10 % (1 %) of charmed quarks (light quarks) [3] and a lepton (ℓ, μ) detection efficiency of 90 % are used. The analysis is performed for low luminosity $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ so pile-up of minimum bias events poses no problem.

Table I: SUGRA parameters for LHC Point D[1].

M_0 (GeV)	$M_{1/2}$ (GeV)	A_0 (GeV)	$\tan(\beta)$	$\mathrm{sgn}(\mu)$
200	100	0	2.0	–

III. DILEPTON INVARIANT MASS ANALYSIS

At LHC Point D gluino pair (gluino squark) production account for 32% (47 %) of the total SUSY cross-section. The dominant decay mode for the gluino is

$$\tilde{g} \rightarrow \tilde{b}_L b, \quad \tilde{b}_L \rightarrow \tilde{\chi}_2^0 b$$

This gives a specific SUSY signature with several b-jets. The possible $\tilde{\chi}_2^0$ decays and their branching fractions are

- BR($\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \ell^+ \ell^-$) = 16 % per lepton species
- BR($\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 q\bar{q}$) = 42 %

If gluinos are pair produced and both neutralinos decay leptonically the signal is:

- 4 b-jets
- 4 isolated leptons

We have 272 000 events of this type per 10 fb^{-1}. If only one $\tilde{\chi}_2^0$ decays leptonically and the other decays into two jets the signal is:

- 6 jets out of which 4 are b-jets
- 2 isolated leptons

There are 694 000 events of this type per 10 fb^{-1}. Both of these decays gives a distinct signature which is easily separated from the Standard Model background. The $\tilde{\chi}_1^0$ is relatively light so the missing transverse energy spectrum is soft and peaks at 80 GeV. However, at this Point in the parameter space, the standard

[1] Point D for the LHC, Point 3 for the NLC and Point 2 for the TEVATRON
[2] A private interface to ISAJET was used

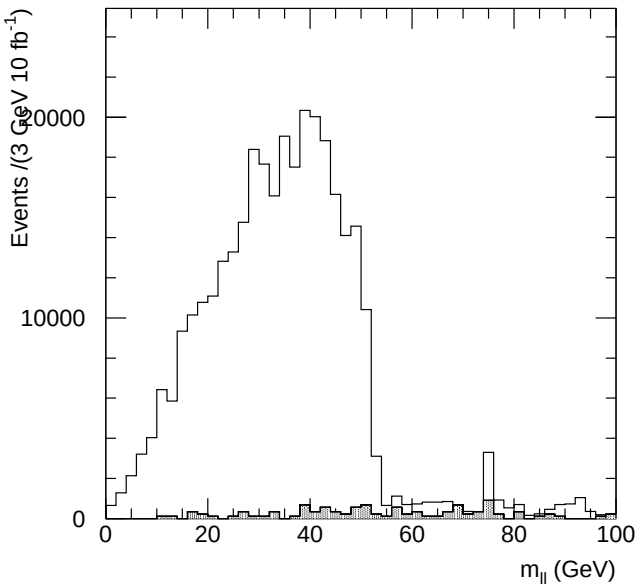

Figure 1: The reconstructed dilepton invariant mass from $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \ell^- \ell^+$. The hatched area is $t\bar{t}$ background.

SUSY cut on $\not{E}_T$ is not needed to distinguish this process from Standard Model backgrounds. The cuts used to extract a clean SUSY cascade decay in this analysis are:

- ≥ 6 jets of which at least 2 are tagged as b-jets
- 2 isolated leptons of opposite sign and same flavour (e or μ),

or:

- ≥ 4 jets of which at least 2 tagged as b-jets
- 4 isolated leptons, two pairs of opposite sign and same flavour (e or μ).

Approximately 2.6 % of the SUSY events pass these cuts. The main background come from $t\bar{t}$ production. The reconstructed dilepton invariant mass spectrum is shown in Fig. 1. There is a sharp drop in the mass spectrum at ≈ 52 GeV. This end-point is the mass neutralino difference $\Delta M_{\tilde{\chi}^0}$. In other SUSY models where the signal is weaker it may be necessary to reduce combinatorial backgrounds, from event with two leptonic $\tilde{\chi}_2^0$ decays, and $t\bar{t}$ background. This background can be reduced by subtracting the invariant mass combinations from opposite sign and opposite flavour lepton pairs. The sensitivity of the invariant mass spectrum to a change in the mass difference was tested with five samples. In these samples $m_{1/2}$ varied between 98 and 102 GeV, which changed $\Delta M_{\tilde{\chi}^0}$ between 51.82 and 53.19 GeV. With only 50000 generated events (3.7 % of 10 fb^{-1}, corresponding to 4 days of LHC running) a measurement of $\Delta M_{\tilde{\chi}^0}$ with an accuracy better than 2 GeV can be achieved. Clearly, the ultimate precision that can be achieved is not statistics limited, but will depend on how well the systematics can be controlled. The dominant error will come from the absolute energy scale of the ATLAS electro magnetic calorimeter which will be controlled to 0.1% using leptonic Z^0 decays [5]. A precision better than 50 MeV is therefore expected[3] for the neutralino mass difference. If the combinatorial background is controlled a measurement of the ratio of BR($\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \ell^- \ell^+$) and BR($\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 q\bar{q}$) can performed by comparing the number of events with 1 and 2 leptonic $\tilde{\chi}_2^0$ decays.

IV. THE $M_{\tilde{\chi}_2^0}$ - $M_{\tilde{\chi}_1^0}$ RELATION TO THE MSUGRA $M_{1/2}$ MODEL PARAMETER

The masses of $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ are both proportional to the common gaugino mass, $m_{1/2}$, at $M_{\rm GUT}$. To see how this neutralino mass difference varies with $m_{1/2}$ a number of SUSY models were generated varying the mSUGRA parameters within the following bounds:

- $95 < M_{1/2} < 105$ GeV,
- $195 < M_0 < 205$ GeV,
- $2 < \tan(\beta) < 10$,
- $\mu < 0$,
- $A_0 = 0$.

The correlation between the neutralino mass difference and $m_{1/2}$ is displayed in Fig. 2. In mSUGRA models a precise determination of the model parameter $m_{1/2}$ can be inferred from a measurement of the neutralino mass difference.

V. CONCLUSION

It has been shown how effectively 3 body decays can be used to measure mass differences. In mSUGRA models the neutralino mass difference ($\Delta M_{\tilde{\chi}^0}$) can be used to precisely infer the mSUGRA model parameter $m_{1/2}$. At LHC Point D, the mass difference between the lightest and next to lightest neutralino can be measured with an expected accuracy of 50 MeV.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

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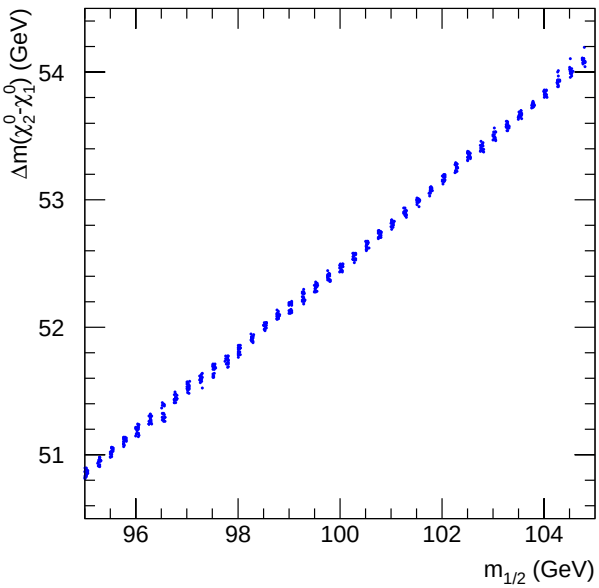

Figure 2: $m_{1/2}$ as function of $\Delta m_{\tilde{\chi}^0} = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$ for a number of mSUGRA models, with the parameters given in section IV

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