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Search for the associated production of charginos and neutralinos in the like-sign dimuon channel with DØ RunIIb data.

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A search for charginos and neutralinos has been performed in $p\bar{p}$ collisions recorded with the D0 detector. The final state with two like sign muons and missing transverse energy is considered. The dataset used in this analysis corresponds to ≈ 3 fb^{-1} integrated luminosity. Preliminary limits on the chargino production cross section times branching ratio into trileptons of about 1 pb have been set.

Preliminary Results

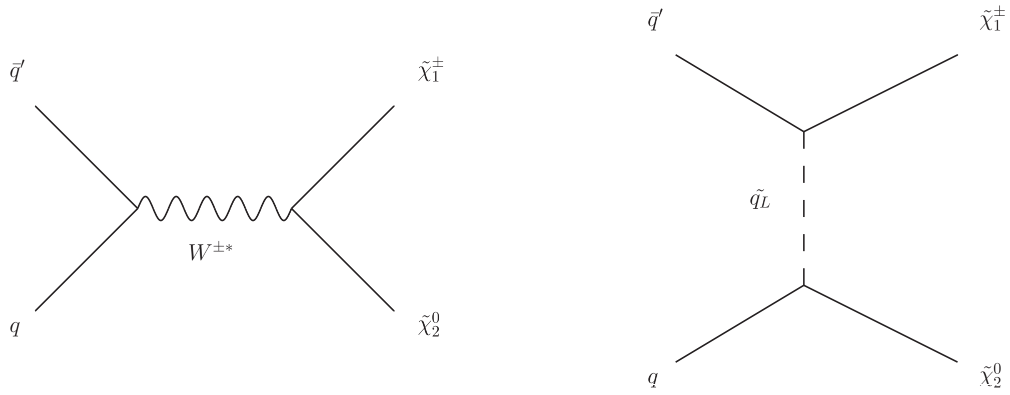

FIG. 1: $\tilde{\chi}_1^\pm$ $\tilde{\chi}_2^0$ production.

I. INTRODUCTION

Supersymmetry (SUSY) is a proposed symmetry between fermions and bosons and predicts the existence of supersymmetric partner for each standard model particle [1]. SUSY provides possible solutions to various standard model topics like hierarchy problem, unification of SU(3), SU(2), SU(1) gauge couplings, quantum gravity and the dark matter. Since we have seen only one half of the particles it means that supersymmetry must be broken at the electroweak scale. In the Minimal Supersymmetric extension of standard model (MSSM) this can be achieved by including explicitly soft SUSY terms into Lagrangian at electroweak scale, which are expected from a high energy breakdown of supersymmetry. One model which provides breaking mechanism is a minimal supergravity SUSY (mSUGRA) based on local supersymmetry requirements, where SUSY is broken in the ground state of hidden sector fields at GUT scale and mediated to the MSSM sector by gravity. This analysis is performed within mSUGRA framework. In R-parity conserving theories the supersymmetric particles (sparticles) are produced in pairs from $p\bar{p}$ collisions, then $\tilde{\chi}_1^0$ which is a stable lightest supersymmetric particle escapes the detection leading to significant missing transverse energy.

The associated production of the chargino $\tilde{\chi}_1^\pm$ and neutralino $\tilde{\chi}_2^0$ can lead to a trilepton final state. Such production can be performed via off-shell W boson or via squark exchange in t channel. The graphs for $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ production are presented on Fig. 1. The graphs for chargino and neutralino decays are presented on Fig. 2.

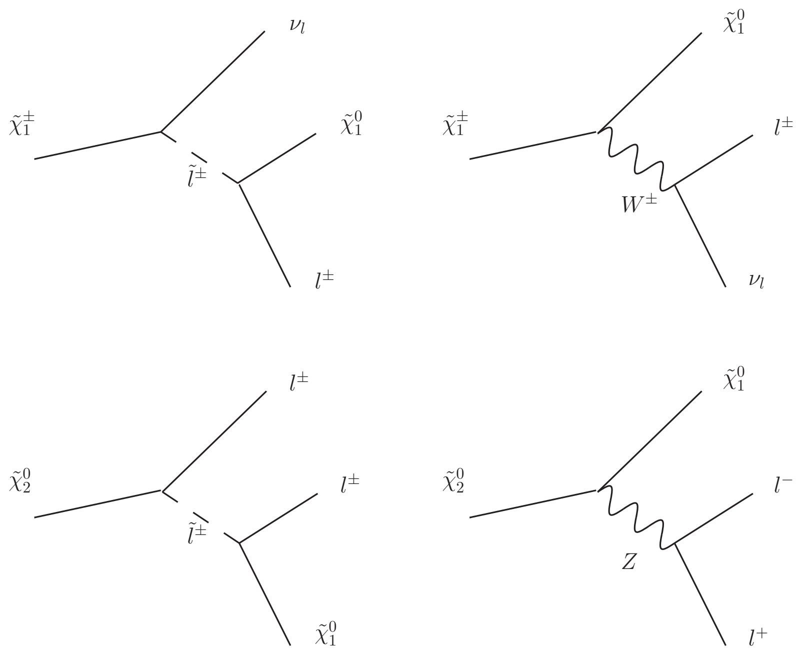

FIG. 2: $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ leptonic decays.

In the final state with three leptons and missing transverse energy the third lepton can have a very low momentum transverse to the $p\bar{p}$ collision axis (p_T), especially when slepton-neutralino mass difference is small and this leads to like sign dilepton signature.

Previous searches in like sign dimuon channel at DØ have set limit on the associated production of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ [2], [3] and were combined with trilepton results [4].

II. DATA AND MONTE CARLO SAMPLES

This search is performed on the data collected from June 9 2006 to December 11 2008 by the DØ detector [5] at the Fermilab Tevatron $p\bar{p}$ collider at a center of mass energy of 1.96 TeV and corresponds to an integrated luminosity 2976 pb^{-1}. The luminosity is calculated by normalizing Monte Carlo to data around the $Z \to \mu\mu$ peak, using the NNLO cross section of 241.6 pb.

Signal Monte Carlo is produced with Pythia 6.319 [6] with LHA input produced with SOFTSUSY 1.9.1 [7]. Cross sections are calculated using PROSPINO 2 [8], with SUSY spectra determined by SOFTSUSY 2.0.14. The branching ratio is calculated using PYTHIA 6.323. Both signal and standard model background Monte Carlo have been generated using CTEQ6L1 parton distribution functions. Then they were processed with full detector simulation. Signal parameter combinations have been generated for trilinear coupling $A_0 = 0$, the ratio of vacuum expectation values of the two Higgs fields $tan\beta = 3$, Higgs mass parameter $\mu > 0$ and chargino masses in the range of 112-168 GeV, see Table I. Major sources of background are $W \to \mu\nu$, $Z/\gamma^* \to \mu\mu$ and multijet background from QCD production. Multijet background was estimated from data as described in Section III. The trigger efficiency of combination of single muon, dimuon and muon+track triggers is taken into account by comparing the p_T distributions in Z/γ^* events in data and Monte Carlo. Charge mis-identification rate of 10% is estimated using $Z/\gamma^* \to \mu\mu$ Monte Carlo events in the region of $\Delta\phi$ between muons greater than 2.9.

TABLE I: Parameters of generated SUSY points.

Point [GeV]	m_0 [GeV]	$m_{1/2}$ [Gev]	$m(\tilde{\chi}_1^0)$ [GeV]	$m(\tilde{\chi}_1^+)$ [GeV]	$m(\tilde{l}_R)$	$\sigma \times BR(3l)$ [pb]
1	77	183	119	116	111	0.4891
2	78	182	118	115	111	0.4800
3	79	181	117	115	111	0.4590
4	80	180	116	114	112	0.4232
5	81	180	116	114	113	0.3917
6	82	179	116	113	113	0.3458
7	83	178	115	112	114	0.2826
8	102	211	143	142	135	0.1714
9	103	210	142	141	136	0.1637
10	104	210	142	141	136	0.1556
11	105	209	141	140	137	0.1441
12	106	208	140	139	137	0.1283
13	107	207	139	139	138	0.0985
14	108	206	139	138	139	0.0245
15	126	240	168	168	160	0.0567
16	128	239	167	167	161	0.0517
17	129	238	166	166	162	0.0482
18	131	236	164	164	163	0.0277

III. EVENT SELECTION

Selected events are required to pass a set of single muon, dimuon, muon+track triggers and to have two like sign muons matched to tracks in the central tracking system with $p_T > 5$ GeV. Each muon must pass anti-cosmic cuts: muon system scintillator hits must be within a ±10 ns range; distance of closest approach of the matched track to the best primary vertex must be <0.16 cm. Δz between muon and primary vertex and Δz between two muons are both required to be less than 1 cm. Number of central fiber tracker hits on muon track must be > 8. Two variables are used to check if a muon is isolated in the calorimeter and tracker:

- $E_T^{0.1<\Delta R<0.4}$ - the sum of the energy depositions in calorimeter cells in the hollow with $0.1 < \Delta R < 0.4$;
- $p_T^{R<0.5}$ - the sum of the transverse momenta of all tracks in the tracker in cone with radius $R = 0.5$,

where $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$. Both muons are required to be tightly isolated in calorimeter and tracker.

The set of requirements listed above forms the pre-selection sample.

The multijet background has been estimated from data as follows. Muons coming from the signal tend to be more isolated than those from multijet background processes. Two samples are formed from data using selection criteria but with two different isolation requirements:

- sample $\mathcal{S}$: both muons are tightly isolated;
- sample $\mathcal{Q}$: one muon is tightly isolated and second muon is loosely isolated.

The multijet background dominates in the region with high values of $\Delta\phi$. The region of $\Delta\phi > 2.9$ is chosen for normalization. The normalization factor is measured as function of p_T of loosely isolated muon by calculating the ratio of number of events in each bin of p_T distributions of $\mathcal{S}$ and $\mathcal{Q}$ samples:

$$R(p_T) = \frac{1}{2} \frac{S(p_T)}{Q(p_T^{looseisolated})} \bigg|_{\Delta\phi>2.9} \tag{1}$$

where $S(p_T)$ is number of tightly isolated muons in $\mathcal{S}$ sample at given p_T, and $Q(p_T^{looseisolated})$ is the number of loosely isolated muons in $\mathcal{Q}$ sample at given p_T. The calculated normalization factor $R(p_T)$ fitted with exponential function is shown on the Fig. 3. The multijet background can be determined now as sample $\mathcal{Q}$ weighted with $R(p_T)$ in the region of $\Delta\phi < 2.9$. The cut $\Delta\phi < 2.9$ is fixed at pre-selection level. In addition to $R(p_T)$ jets multiplicity normalization has been performed.

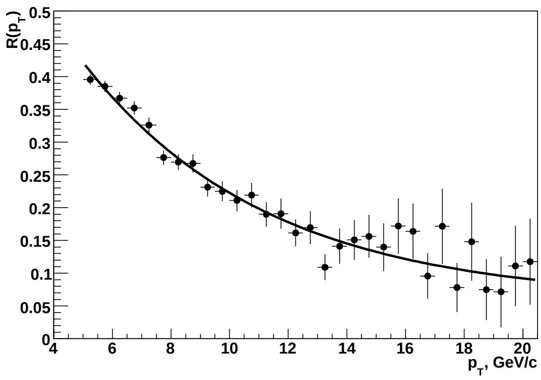

FIG. 3: Normalization function $R(p_T)$

In order to extract the signal events the selection criteria have been optimized to obtain the best expected limit on $\sigma(p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \times BR(3l)$. SUSY point 4 is used for optimization.

Transverse momenta (p_T), Fig. 4, 5. Cuts on the muons p_T is used to reject multijet background.

- $p_{T1} > 21$ GeV/c;
- $p_{T2} > 10.5$ GeV/c;
- $p_{T2} < 60$ GeV/c;

Invariant mass of opposite sign pair, Fig. 6. If third muon is found in event then a cut on $M_{OS} \in [10, 65]$ GeV/c^2 is applied. This cut rejects events Z/γ^*, WZ and ZZ events.

Invariant mass of like sign pair, Fig. 7. The cut on $M_{SS} \in [15, 120]$ GeV/c^2 is effective against W and WZ background.

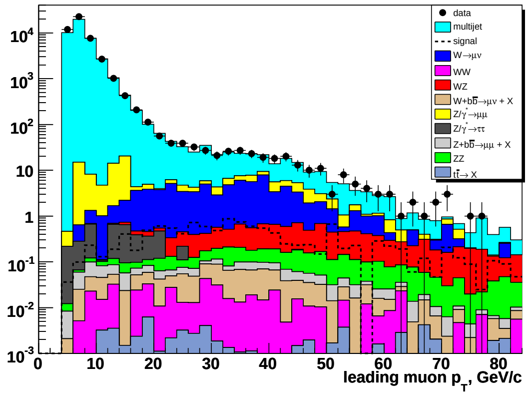

FIG. 4: Leading muon p_T at pre-selection level.

Missing transverse energy $\not\!\!E_T$, Fig. 8. The $\tilde{\chi}_1^0$ produced in $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ decays is a stable particle which escapes the detector leading to large amount of missing energy observed.

Significance of $\not\!\!E_T$, Fig. 9. Mismeasurements in the calorimeter can lead to artificial $\not\!\!E_T$. To remove this background, a significance of $\not\!\!E_T$ has been developed. This variable is defined as:

$$Sig(\not\!\!E_T) = \frac{\not\!\!E_T}{\sqrt{\sum E_{jet}\sigma^2_{proj}}} \tag{2}$$

where σ_{proj} is jet energy resolution projected onto $\not\!\!E_T$ direction. The requirement of $Sig(\not\!\!E_T) > 5.5$ GeV is used in event selection.

Transverse mass, Fig. 10. The cut on transverse mass $15 < M_{T2} < 80$ GeV/c^2 is calculated using $\not\!\!E_T$ and p_T of next to leading muon is introduced to reject events from W and diboson background.

$$M_{T2} = \sqrt{2\not\!\!E_T \cdot p_{T2}(1 - cos\Delta\phi_{(\not E_T,\mu 2)})} \tag{3}$$

$\mathbf{\not\!\!E_T \times p_{T2}}$, Fig. 11. The cut of simple product $\not\!\!E_T \times p_{T2} > 500$ GeV^2/c is effective against multijet background and background from W decays.

The number of events for data and background at pre-selection and final stages of selection are summarized in Table II. The number of signal events at pre-selection and final stages of selection are summarized in Table III.

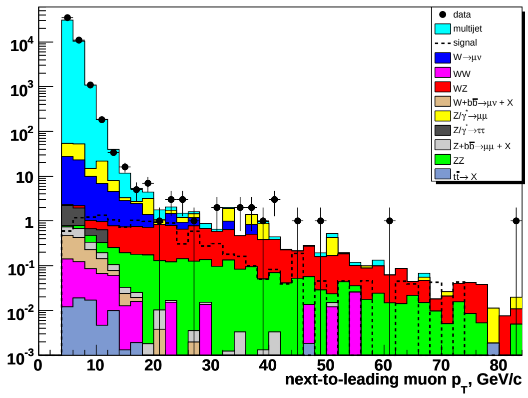

FIG. 5: Next to leading muon p_T at pre-selection level.

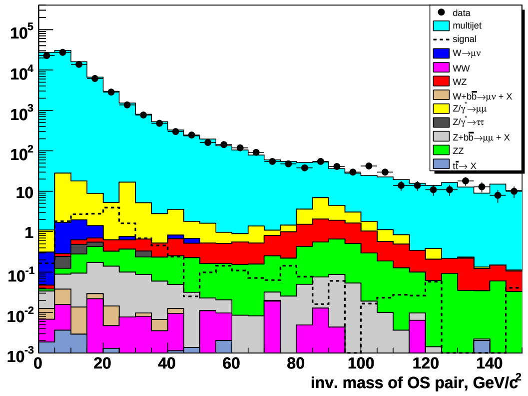

FIG. 6: Invariant mass of opposite sign muon pair at pre-selection level.

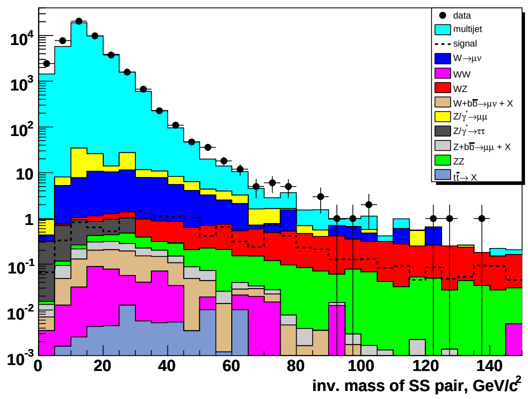

FIG. 7: Invariant mass of like sign muon pair at pre-selection level.

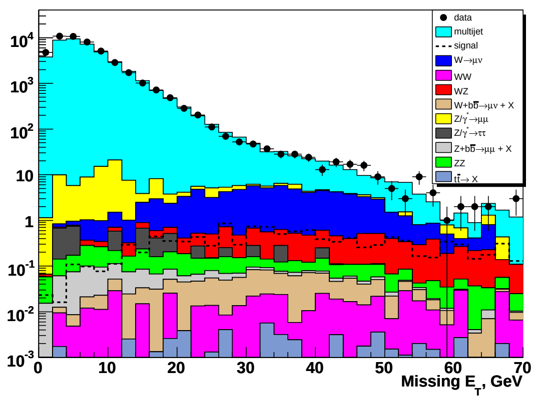

FIG. 8: Missing transverse energy at pre-selection level.

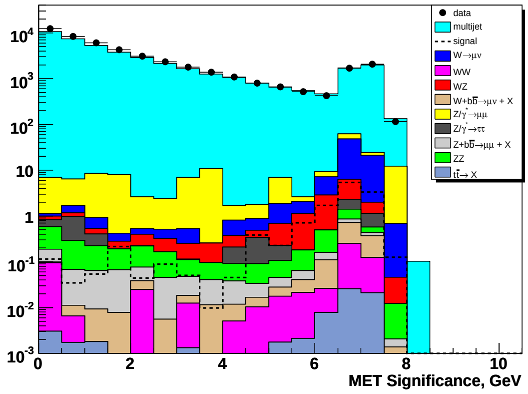

FIG. 9: Significance of missing transverse energy at pre-selection level.

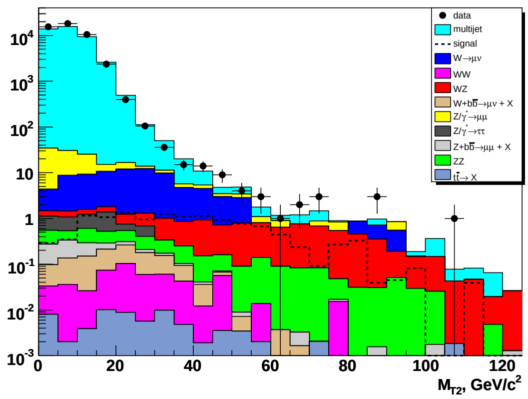

FIG. 10: Transverse mass computed using $\not{E}_T$ and p_{T2} at pre-selection level.

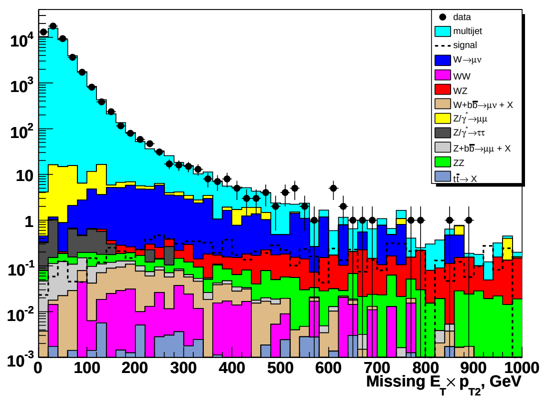

FIG. 11: Product of missing transverse energy and second muon p_T at pre-selection level.

TABLE II: Number of data and background events at pre-selection and final stages of selection

Sample	Pre-selection	Final
Multijet	43288 ± 141	2.1 ± 0.4
$W \to \mu\nu$	70.3 ± 3.7	3.1 ± 0.9
$Z/\gamma^* \to \mu\mu$	84.5 ± 12.3	1.3 ± 0.3
WZ	10.2 ± 0.3	1.4 ± 0.1
WW	0.53 ± 0.07	0.07 ± 0.02
Wbb	0.90 ± 0.03	0.02 ± 0.01
ZZ	2.61 ± 0.11	0.14 ± 0.4
$t\bar{t}$	0.07 ± 0.01	0.01 ± 0.003
$Z/\gamma^* \to \tau\tau$	3.1 ± 0.7	0
Zbb	0.73 ± 0.02	0.007 ± 0.004
$Sum(Bkg)$	43461 ± 142	8.1 ± 1.8
$Data$	47000	7

TABLE III: Number of signal events at dat pre-selection and final stages of selection.

SUSY point	Pre-selection	Final
1	15.04 ± 0.81	3.03 ± 0.40
2	15.68 ± 0.81	4.22 ± 0.45
3	13.84 ± 0.75	3.71 ± 0.42
4	12.51 ± 0.70	4.02 ± 0.43
5	13.77 ± 0.71	4.81 ± 0.44
6	14.86 ± 0.73	5.70 ± 0.47
7	14.21 ± 0.63	5.79 ± 0.41
8	6.37 ± 0.29	1.60 ± 0.16
9	5.43 ± 0.25	1.73 ± 0.15
10	5.76 ± 0.26	1.99 ± 0.17
11	5.75 ± 0.29	2.18 ± 0.19
12	5.23 ± 0.24	2.16 ± 0.16
13	6.50 ± 0.26	2.71 ± 0.17
14	1.76 ± 0.06	0.56 ± 0.03
15	2.56 ± 0.11	0.69 ± 0.06
16	2.30 ± 0.10	0.72 ± 0.06
17	2.16 ± 0.10	0.72 ± 0.06
18	1.75 ± 0.07	0.61 ± 0.04

IV. SYSTEMATIC UNCERTAINTIES

We have assessed systematic uncertainties from detector simulation, modeling of the physics processes and multijet background estimation: luminosity uncertainty (6%), PDF uncertainty ($< 4\%$), jet energy scale uncertainty (1%), muon identification and track matching systematics combined to 3% uncertainty, sign misidentification uncertainty (10%), multijet modeling uncertainty (30%).

V. RESULTS

After all selection 7 candidate events are found in data and they are consistent with the expected background of 8.1 ± 1.8 events, no excess of SUSY events is observed. The limit on $\sigma(p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \times BR(3l)$ has been calculated for analyzed SUSY points using ROOT class TLimit based on CLS method [9]. Observed and expected limits as function of chargino mass are presented on Fig. 12. SUSY points 5, 7, 13, 19 are chosen (see Table I).

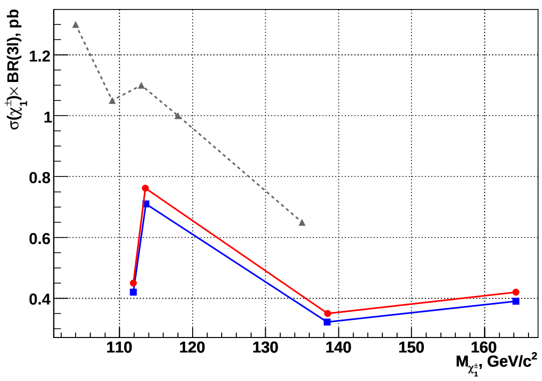

FIG. 12: Observed limit from previous result (line+triangles), observed (line+boxes) and expected (line+circles) limits on $\sigma(p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \times BR(3l)$.

The limits for different regions of $m_0 - m_{1/2}$ scan are shown on Fig. 13, 14, 15.

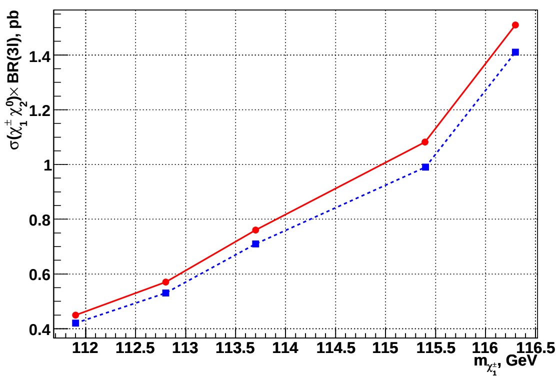

FIG. 13: Observed (dash line) and expected (solid line) limits on $\sigma(p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \times BR(3l)$. $m_0 = 77 - 83, m_{1/2} = 178 - 183$

VI. CONCLUSION

Preliminary results obtained in this analysis using $\approx 3fb^{-1}$ dataset show noticeable improvement compared to previous results [3]. This observed improvement is basically due to having more luminosity. The major source of uncertainty is multijet background modeling. The major sources of background are multijet background and $W \to \mu\nu$

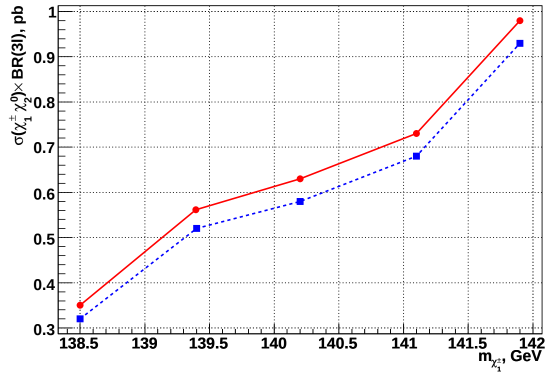

FIG. 14: Observed (dash line) and expected (solid line) limits on $\sigma(p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \times BR(3l)$. $m_0 = 101 - 108, m_{1/2} = 206 - 211$

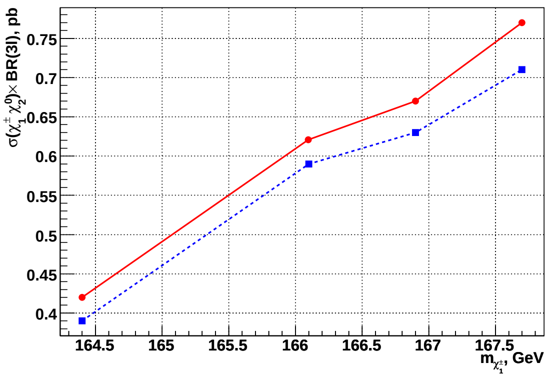

FIG. 15: Observed (dash line) and expected (solid line) limits on $\sigma(p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \times BR(3l)$. $m_0 = 126 - 131, m_{1/2} = 236 - 240$

decays. The 7 events observed in this analysis are consistent with 8.1 ± 1.8 events expected from background. Obtained results are to be combined with RunIIa data and with latest results of trilepton analysis [10].

Acknowledgments

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