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Study of Chargino-Nutralino Pair Production like Higgsinos and Gauginos at The LHC with Three Leptons Final State and Missing Transverse Momentum

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Abstract:

The calculation of chargino-nutralino pair production at the LHC with $\sqrt{s}$ = 14 TeV had been studied. Different benchmark points are evaluated for the chargino-nutralino pair production using MSSM for four conditions on mass parameters. The results were compared with the latest data recorded by the LHC at $\sqrt{(s)}$ = 8, 13, 14 TeV for pp collisions. In the minimal supersymmetric extension of the SM (MSSM) the mass parameters for the bino, wino, and higgsino states represented by M1, M2, and μ. Our results depend on the nature of the chargino-nutralino pair production and its masses. In case of light higgsino like sleptons the total cross section produced at small x, while for gauginos like s-quarks produced at large x due to the fact that gaugino constrained by CMS and ATLAS as heavier than 1 TeV. Assuming that the lightest supersymmetric particle (LSP) x ̃_1^0 is stable with R-parity conservation, it is a well-motivated to viable dark-matter candidate. Two scenarios of chargino-nutralino pair production are considered in this search. The first scenario Gaugino like with two conditions on the wino-bino and higgsino mass parameters [(M1 < M2 < μ) and (M1 < M2 < −μ)]. The second scenario Higgsino like with two conditions on the wino-bino and higgsino mass parameters [(M1 < −μ < M2) and (−μ < M1 < M2)]. Also, the effect of the sign and value of μ on the total cross sections for higgsinos and gauginos was represented.

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1. Introduction

While the Standard model SM cannot give a good explanation for some physics phenomenology one need to go beyond the Standard Model (BSM). The LHC is actively searching for physics (BSM) depend on the predictions of specific models and also some interesting research in the field of high energy [1]. The Minimal Supersymmetric Standard Model (MSSM) [2] is one of candidates of Beyond Standard Model (BSM) that relays on Supersymmetry (SUSY) [3]. The well-motivated extension of the Standard Model (SM) is the MSSM which can solve a huge number of shortcomings in SM, Such as the inability to explain the fundamental parameters of the standard model, the strong CP problem, neutrino oscillations, matter–antimatter asymmetry, and the nature of dark matter and dark energy [4,5]. It can predict with the fermionic partners charged and neutral gauge (gauginos) and higgs boson (higgsinos). The lightest neutralino $\tilde{x}_1^0$ is a good candidate for the Cold Dark Matter (CDM) [3,6]. In addition, the MSSM has more gifts for us such as explains Higgs hierarchy (Naturalness) and gauge coupling unification. One of the naturalness problems that we are faced in embedded the SM within a more fundamental theory including gravity with a characteristic scale of order the Planck mass MP is the hierarchy problem. In supersymmetry which mean space time symmetry related to bosons and fermions, the new scalar bosons can ensure the stability of hierarchy between the weak and the Planck scales. In the SM, the Higgs mass receives contribution from one-loop radiative corrections. This contribution is proportional to the square of the momentum running in the loop and can be set to the cut-off scale or larger than that. With the cut-off scale of the order of the GUT scale, MG ≈ 1016 GeV, Higgs mass is not protected to be of Order (100 GeV) to break the electroweak symmetry. In SUSY, the loop diagrams are quadratically divergent cancel, term by term against the equivalent diagrams involving superpartners [4].

ATLAS and CMS collaborations set limits on the direct production of a chargino and neutralino ($pp \rightarrow \tilde{x}_1^{\pm} \tilde{x}_2^0$) with the subsequent decays $\tilde{x}_1^{\pm} \rightarrow \tilde{x}_1^0\ W^{\pm}$ and $\tilde{x}_2^0 \rightarrow \tilde{x}_1^0\ Z$, resulting a three lepton signature [7–11]. The results could agree with the MSSM in case of the charginos $\tilde{x}_{1,2}^{\pm}$ and neutralinos $\tilde{x}_{1,2,3,4}^0$ masses observed in several-hundred GeV range. The highest sensitivity comes from multi-lepton final states. The predictions for the

W Z + E_T^miss final state are important compare with the experimental results. The cross sections for the production of supersymmetric (SUSY) measure at LHC which have more precise theoretical calculations at QCD [12–19]. One of the most important goals at LHC is to search for chargino-nutralino pair production [20–25], which carried out through simplified models [26, 27]. Furthermore, the theoretical assumptions should be not more simplified [28].

In this study, we analyze the chargino-nutralino pair production with its decay at the √s = 14 TeV, where M1, M2, and μ (the mass parameters for the bino, wino, and higgsino , respectively) are taken as a free parameters. Considering the current limits on the MSSM parameter space. The Mathematica packages SARAH [29] which can be compiled with SPheno 4.0.3 [30] are used to build the model. Two scenarios were represented in our work. The first scenario is study the chargino-nutralino pair like Gauginos [(M1 < M2 < μ) and (M1 < M2 < −μ)]. The second scenario is study the chargino-nutralino pair like Higgsinos, [(M1 < −μ < M2) and (−μ < M1 < M2)]. We generate the events and calculate the matrix element by MadGraph 5 [31] and used Pythia 8.3 and Delphes 3 [32] to simulate the radiation, fragmentation and harmonization effect in the initial-final state and detector response, Finally we recorded the expected limits from the first 139 fb−1 at the LHC √s = 14 TeV. This paper described as, we begin with a short review of the MSSM (supersymmetric version of the standard model) parameters and particle spectrum in Sec. 2. The results of our analysis for the pair production of Higgsino and Gaugino are described in Sec. 3 i.e. the mass limits and cross sections for the two scenarios, as well as our expectation to the LHC at √s = 14 TeV. Finally, we conclude our work in Sec 4.

2. ANALYTICAL APPROACH

In BSM models the non-coloured charginos, neutralinos and sleptons are considered as the lightest supersymmetric particles, which have low masses and need small cross sections for production. A more useful reaction for charginos-neutralinos pair production is $pp \rightarrow \tilde{x}_1^{\pm}\,\tilde{x}_2^{0}$ which decay to $\tilde{x}_1^{\pm} \rightarrow \tilde{x}_1^{0}\;\ell^{\pm}\;\nu_l^{(-)}$ and to $\tilde{x}_2^{0} \rightarrow \tilde{x}_1^{0}\;\ell^{+}\;\ell^{-}$ with three lepton in final state [33]. This reaction has been represented in several Tevatron [34] analyses. Increasing energiesand luminosities play an important role to extend the range of sensitivity [35, 36]. The chargino/neutralino mass eigen-states can describe in terms of two-component Weylspinors [14], as

$$\tilde{x}_i^+ = V_{ij}\,\psi_j^+ \text{ , basis: } \psi_j^+ = (\text{-i}\lambda^+ ,\psi_{H_2}^+)$$

$$\tilde{x}_i^- = U_{ij}\,\psi_j^- \text{ , basis: } \psi_j^- = (\text{-i}\lambda^- ,\psi_{H_1}^-)$$

$$\tilde{x}_i^0 = N_{ij}\,\psi_j^0 \text{ , basis: } \psi_j^0 = (\text{-i}\lambda' ,-\text{i}\lambda^3,\psi_{H_1}^0,\psi_{H_2}^0) \qquad (1)$$

Where The vector bosons (V = γ/Z/W) in the s-channel couple to the gaugino (λ) and higgsino (ψ_H) components of the charginos and neutralinos. The combining of the two component Weyl spinors lead to constructed the four-component Dirac-spinors and Majorana spinors ($\tilde{x}_i^\pm, \tilde{x}_i^0$) [2, 37]. The mixing matrices U, V and N are defined such that the chargino and neutralino masses are real and positive.

Using four bilinear charges $Q_{\alpha\beta}$ [38] the transition matrix element can be written as,

$$Q_{LL} = \frac{1}{\sqrt{2}\,s_W^2}\left[\frac{N_{j2}^* V_{i1} - N_{j4}^* V_{i2}/\sqrt{2}}{s-M_W^2} + \frac{V_{i1}}{c_W}\frac{N_{j1}^*(e_{\bar{q}} - I_{3\bar{q}})\,s_W + N_{j2}^*\,I_{3\bar{q}}\,c_W}{u-m_{\tilde{q}}^2}\right]$$

$$Q_{LR} = \frac{1}{\sqrt{2}\,s_W^2}\left[\frac{N_{j2}\,U_{i1}^* - N_{j3}\,U_{i2}^*/\sqrt{2}}{s-M_W^2} + \frac{U_{i1}^*}{c_W}\frac{N_{j1}\,(e_{\bar{q}} - I_{3\bar{q}})\,s_W + N_{j2}\,I_{3\bar{q}}\,c_W}{t-m_{\tilde{q}}^2}\right]$$

$$Q_{RL} = Q_{RR} = 0, \qquad (2)$$

where $e_{\bar{q}}$ and $I_{3\bar{q}}$ are the electric-charges, third-isospin-components of the exchanged s-quarks, respectively. Furthermore, the Mandelstam variables are defined as (t = $(p_q - p_{\tilde{x}_i})^2$) , (u = $(p_q - p_{\tilde{x}_j})^2$) , (s = $(p_q + p_{\bar{q}})^2$) in the partonic frame $p_q, p_{\bar{q}}$ are the momenta of initial quarks, $p_{\tilde{x}_i}, p_{\tilde{x}_j}$ represent the same for $\tilde{x}_i^\pm$ and $\tilde{x}_j^0$ respectively. and $c_W/\,s_W$ are the cosine/sine of the weak mixing angle. The partonic cross section averaging reads [14]

$$\frac{d\hat{\sigma}}{dt} = \left[q\bar{q}^{(\prime)} \longrightarrow \tilde{x}_i\tilde{x}_j\right] = \frac{\pi\alpha^2}{3s^2}$$

$$\left[(|Q_{LL}|^2 + |Q_{RR}|^2)\,u_i\,u_j + (|Q_{LR}|^2 + |Q_{RL}|^2)\,t_i\,t_j + 2Re(Q_{LL}^* Q_{LR} + Q_{RR}^* Q_{RL})\,m_{\tilde{x}_i}\,m_{\tilde{x}_j}\,s\right] \quad (3)$$

Which are expressed in terms of four helicity charges Q_{LL}, Q_{LR}, Q_{RL}, Q_{RR}. Where $t_{ij} = t - m^2_{x_{ij}}$ and $u_{ij} = u - m^2_{x_{ij}}$.

3. NUMERICAL RESULTS FOR CHARGINO-NUTRALINO PAIR PRODUCTION

For the first scenario (Higgsino like), SUSY theories assume that the higgsinos pair produced at small masses. Furthermore the mass of lightest neutralino, the Lightest-SUSY-Particle (LSP) ($\tilde{x}^0_1$), the lightest chargino ($\tilde{x}^{\pm}_1$) and the next-to-lightest-neutralino ($\tilde{x}^0_2$), are closed. The Experimental Analyses for this production consider three main processes [39]. The first two processes produce $\tilde{x}^{\pm}_1$ $\tilde{x}^0_2$, while the third process is $x^+ x^-$. Then the $\tilde{x}^{\pm}_1$ and $\tilde{x}^0_2$ will decay to the lighter $\tilde{x}^0_1$ and Z or $W^{\pm}$ boson, respectively.

The higgsino-pairs $\tilde{x}^{\pm}_1$ $\tilde{x}^0_2$ masses were represented by ATLAS and (CMS) collaboration at integrated luminosity of 139 (36) fb^{-1} [39, 40] to be up to 193 (168) GeV which will decayto light nutralino $\tilde{x}^0_1$ of mass up to 9 (20) GeV and electroweak W and Z gauge bosons. In the high-luminosity phase of the LHC (HL-LHC) with 3000 fb^{-1} at a center-of-mass energy 14 TeV, the mass reach is expected to extend to 360 GeV.

The chargino-nutralino pair production $\tilde{x}^{\pm}_1$ $\tilde{x}^0_2$ and $\tilde{x}^0_1$ like higgsinos can be obtained at limit of $\mu \leq M_1$ and M_2. For our analysis we set *(tan β)* as a free parameter and (μ) between 100 GeV and 500 GeV. Our calculations of total cross sections are implemented using MadGraph [31].

For the second scenario (Gauginos like), which produced with a large gaugino component, the chargino $\tilde{x}^{\pm}_1$ and neutralino $\tilde{x}^0_2$ considered as wino-like while the LSP ($\tilde{x}^0_1$) is bino-like. The winos will decay through these states into the LSP. The particle spectrum for masses in this case can be studied within the MSSM framework. By choosing a large value for $\mu \gg M_2$ then the large gaugino content can be achieved. Based on an integrated LHC luminosity of 36 fb^{-1}, the ATLAS (CMS) collaboration have recorded, the mass-degenerate of wino pairs $\tilde{x}^{\pm}_1$ $\tilde{x}^0_2$ up to masses of 1100 (800) GeV, which decaying to significantly lighter pure binos $\tilde{x}^0_1$ of mass below 550 (300) . The chargino-nutralino pair production $\tilde{\chi}_1^{\pm}\ \tilde{\chi}_2^0$ wino-like charginos and neutralinos and $\tilde{\chi}_1^0$ a bino-like LSP is obtained using again the public code SPheno 4.0.3 and at small value of bino mass parameter M_1 GeV, and large value of wino mass parameter M_2.

3.1. The Total Cross-Sections

The total cross-section for the higgsinos like chargino-nutralino production was calculated and represented in Fig. (1). As shown the −ve sign for μ represent a best expected results for the total cross section. The data for the smallest μ (i.e.: $-\mu <$ $M_1 < M_2$) are more Compatible with the expected data calculating by LHC at $\sqrt{s}$ = 13 and 14 TeV [41, 42]. Also, the data for ATLAS at $\sqrt{s}$ = 8 TeV was compared [43]. The total cross-sections for gauginos like chargino neutralino pair was calculated and represented in Fig. (2). As shown the –ve sign for μ give the best compatible results for the expected data by LHC at $\sqrt{s}$ = 13 and 14 TeV [41,42]. Also, the data for ATLAS at $\sqrt{s}$ = 8 TeV was compared.

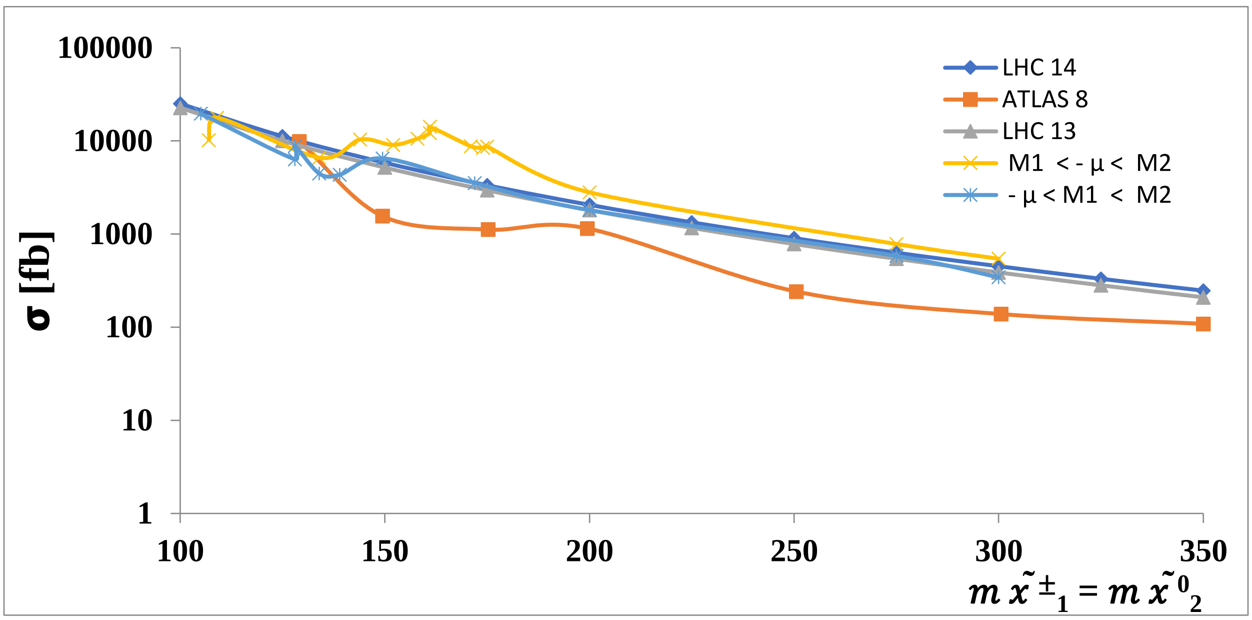

Figure (1)

Fig. (1): Total cross-section for Chargino-Nutralino like Higgsinos at the LHC of $\sqrt{s}$ = 14 TeV center-of-mass energy function of ($m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{\chi}_2^0}$) for two condition of μ The result are compared with the latest expirement result for ATLAS at $\sqrt{s} = 8$ TeV (red) line, also the LHC result at $\sqrt{s}$ = 13, 14 TeV was represented by (blue and green) lines respectively.

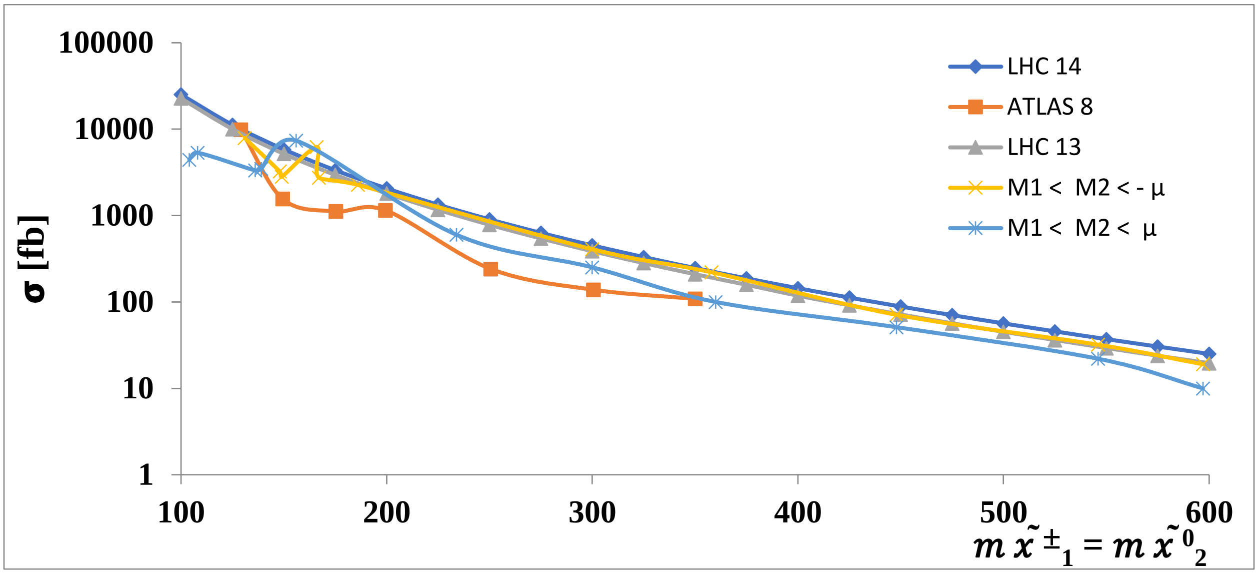

Figure (2)

Figure (2): Total cross-section for Chargino-Nutralino like Gauginos at the LHC of $\sqrt{s}$ = 14 TeV center-of-mass energy for large μ (i.e: ($M_1 < M_2 < \mu$) , ($M_1 < M_2 < -\mu$)). The results are compared with the latest experiment results for ATLAS at $\sqrt{s}$ = 8 TeV (red) line, also the LHC result at $\sqrt{s}$ = 13, 14 TeV was represented by (blue and green) lines respectively.

3.2. The Benchmark-points

The electro-weak couplings and physical masses of the SUSY particles compute by running the program SPheno 2.2.3 [44]. We choose two scenarios of our numerical studies, Gauginos like ($M_1 < M_2 < -\mu$), ($M_1 < M_2 < +\mu$) and Higgsinos like($M_1 < -\mu < M_2$), ($-\mu < M_1 < M_2$). Then we take $\tan\beta$, μ, a light gaugino mass parameter $m_{1/2}$, a lower scalar mass parameter m_0 and trilinear coupling A_0 as a free parameter. The results are calculated at at $\sqrt{s}$ = 14 TeV with integrated luminosity of 139 fb^{-1}. The expected results for the mass limits of $\tilde{\chi}_1^{\pm} = \tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ at $\sqrt{s}$ = 14 TeV represented in the below tables in GeV. A summary of some Benchmark (BM1, BM2, BM3, ……) points for all scenarios considered here is presented in Tables (1,2,3,4) , Where BM refer to the Benchmark points.

Table 1: MSSM model parameters for 11 benchmark points (BM1, BM2…) at ($M_1 < M_2 < -\mu$).

Parameter	BM 1	BM 2	BM 3	BM 4	BM 5	BM 6	BM 7	BM 8	BM 9	BM 10	BM 11
A_0 (GeV)	5.11	5.6	5	5.5	5	5.11	5.6	5.5	5	5	5.9
$\tan\beta$	13	8	9	17	22	18	14	18	20	20	15
μ (GeV)	-600	-600	-581	-465	-480	-417	-398	-477	-477	-497	-465
$m_{\tilde{\chi}_1^0}$ (GeV)	210	270	299	240	205	169	150	153	135	133	118
$m_{\tilde{\chi}_2^0}$ (GeV)	597	546	448	358	300	186	167	166	149	148	131
$m_{\tilde{\chi}_1^\pm}$ (GeV)	597	546	448	358	300	186	167	166	149	148	131
m_{h° (GeV)	125	124	124	124	124	124	125	126	125	125	125
m_{A° (GeV)	563	573	562	568	722	713	498	616	696	653	563

Table 2: MSSM model parameters for 8 benchmark points (BM1, BM2 …) at ($M_1 < M_2 < \mu$).

Parameter	BM 1	BM 2	BM 3	BM 4	BM 5	BM 6	BM 7	BM 8
A_0 (GeV)	7.4	6.5	5.9	7.3	5.8	6.7	6	5.8
$\tan\beta$	20	17	19	11	11	17	19	19
μ (GeV)	650	630	560	498	434	499	425	491
$m_{\tilde{\chi}_1^0}$ (GeV)	300	250	297	210	205	139	123	59
$m_{\tilde{\chi}_2^0}$ (GeV)	600	520	438	340	300	156	136	104
$m_{\tilde{\chi}_1^\pm}$ (GeV)	600	520	438	340	300	156	136	104
m_{h° (GeV)	125	124	124	125	125	125	125	125
m_{A° (GeV)	740	574	595	649	591	650	574	595

Where Table (1, 2) represent the limit of mass for chargino $\tilde{\chi}_1^\pm$, nutralino $\tilde{\chi}_2^0$, and the lightest nutralino $\tilde{\chi}_1^0$ as a gauginos like. Also the free parameters of MSSM are recorded for two conditions on mass parameters ($M_1 < M_2 < -\mu$) and ($M_1 < M_2 < \mu$).

Table 3: (part 1) MSSM model parameters for the first 9 benchmark points (BM1, BM2…)

at ($M_1 < -\mu < M_2$)

Parameter	BM 1	BM 2	BM 3	BM 4	BM 5	BM 6	BM 7	BM 8	BM 9
A_0 *(GeV)*	6	5.5	5	6	5.3	5.9	5.5	5	5.4
$tan\beta$	15	13	18	17	23	19	16	19	16
μ *(GeV)*	-171	-100	-121	-133	-109	-102	-105	-174	-115
$m_{\tilde{x}_1^0}$ *(GeV)*	125	64	87	93	80	67	64	126	84
$m_{\tilde{x}_2^0}$ *(GeV)*	184	117	141	145	130	119	119	185	-136
$m_{\tilde{x}_1^\pm}$ *(GeV)*	174	107	126	134	110	105	108	175	119
m_{h° *(GeV)*	124	124	125	125	124	125	126	125	125
m_{A° *(GeV)*	507	553	491	483	614	536	584	594	557

Table 3: (part 2) The other 9 benchmark points (BM1, BM2…) at ($M_1 < -\mu < M_2$).

Parameter	BM 10	BM 11	BM 12	BM 13	BM 14	BM 15	BM 16	BM 17	BM 18
A_0 *(GeV)*	5	6	5.3	5.9	5.5	5	5.4	5	4.9
$\tan\beta$	20	14	13	14	9	15	21	15	17
μ *(GeV)*	-108	-153	-153	-157	-165	-172	-143	-134	-157
$m_{\tilde{\chi}_1^0}$ *(GeV)*	64	107	110	114	121	123	100	95	113
$m_{\tilde{\chi}_2^0}$ *(GeV)*	121	162	168	171	175	179	156	149	172
$m_{\tilde{\chi}_1^\pm}$ *(GeV)*	111	152	157	161	166	170	144	136	160
m_{h° *(GeV)*	125	125	125	124	124	124	125	125	125
m_{A° *(GeV)*	638	553	573	436	515	501	576	554	603

Table 4: MSSM model parameters for the 8 benchmark points (BM1, BM2…) at ($-\mu < M_1 < M_2$).

Parameter	BM 1	BM 2	BM 3	BM 4	BM 5	BM 6	BM 7	BM 8
A_0 (GeV)	4	4.7	4.2	5	4.3	4	4.8	4
$\tan\beta$	15	16	15	13	13	14	16	16
μ (GeV)	-171	-127	-133	-99	-131	-117	-125	-135
$m_{\tilde{\chi}_1^0}$ (GeV)	148	106	113	85	109	94	104	114
$m_{\tilde{\chi}_2^0}$ (GeV)	-190	-149	-155	-120	-151	-138	-146	-154
$m_{\tilde{\chi}_1^\pm}$ (GeV)	171	128	135	105	133	121	127	138
m_{h° (GeV)	125	125	124	125	125	124	125	125
m_{A° (GeV)	414	422	477	422	427	458	461	473

As shown Table (3, 4) represent the limit of mass for chargino $\tilde{\chi}_1^\pm$, nutralino $\tilde{\chi}_2^0$, and the lightest nutralino $\tilde{\chi}_1^0$ as a Higgsinos like. Also the free parameters of MSSM are recorded for two conditions on mass parameters ($M_1 < -\mu < M_2$) and ($-\mu < M_1 < M_2$).

Conclusion

We conclude our predictions for chargino nutralino pair production at the LHC √s = 14 TeV as higgsinos and gauginos like. The total cross section was calculated and presented for two scenarios. Also, the effect of the vale and sign of μ on the total cross section had been studied. It was shown that our results for chargino-nutralino pair production as higgsinos like were compatible with the latest experiment results where the SUSY theories assumption for this spectra small mass of x. In case of gauginos like i.e a large gaugino component for the produced neutralinos-charginos and large mass of x, also the results were compatible with the latest experiment. Our expected mass limit for the next run at LHC $\sqrt{s}$ = 14 TeV were represented. The recently search on LHC constrained the gauginos which are s-quarks and gluinos like to region of TeV. Where the mass limits on higgsinos from the LHC are relatively weak, they can be as light as a few-hundreds of GeV. The different sign on μ results represented only small compatible of the total cross sections with the expected results by the LHC.

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دراسة انتاج زوج من الشارجينو- نيوترالينو فى حالة الهجزينو والجيجينو مع الليبتونات والطاقات المستعرضة المفقودة فى نواتج التحلل النهائيه فى المصادم الهادرونى الكبير

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الملخص العربى

تمت دراسة حساب إنتاج زوج من شارجينو-نوترالينو في المصادم الهادرونى الكبير عند طاقة 14 تيرا الكترون فولت. لقد تم تقييم النسب المتفرعة لانتاج زوج من شارجينو-نوترالينو باستخدام نموذج الحد الأدنى من تمديد النموذج القياسى لأربعة شروط على معاملات الكتلة . حيث تمت مقارنة النتائج مع أحدث البيانات التي سجلها المصادم الهادرونى الكبير عند الطاقات = 8 , 13 , **14** تيرا الكترون فولت فى تصادم بروتون – بروتون . يشير كلا من وينو وبينو الى مجالات القياس (الجيج بوزون) بينما يشير هيجزينو إلى الجسيم الشريك فائق التماثل فى مجال الهيجز بوزون. في نموذج الحد الأدنى من الامتداد الفائق التناسق للنموذج القياسى يتم تعريف معاملات الكتلة لحالات وينو وبينو وهجزينو ممثلة بـ **M1** و **M2** و μ على التوالى. تعتمد نتائجنا على طبيعة إنتاج زوج من الجسيمات فائقة التماثل شارجينو-نوترالينو و كتلتها. في حالة الهجزينو الخفيف مثل جسيمات الشركاء فائقه التماثل لليبتونات عديمة الشحنة تكون المقطع النووى العرضى لانتاجها عند كتلات صغيره فى نطاق الجيجا الكترون فولت ,بينما فى حالة الجيجينو مثل جسيمات الشركاء فائقه التماثل للكواركات ذات الشحنه تكون المقطع النووى لانتاجها عند كتلات كبيرة فى نطاق التيرا الكترون فولت**.** بافتراض أن أخف جسيم فائق التناظر ثابت مع الحفاظ على تكافؤ **R** يعتبر مرشح جيد لوجود الماده المظلمه. فى هذا البحث تم دراسة اربعة شروط فيزيائية على معاملات الكتلة **M1** و **M2 M2** و μ **{ $(M1 < M2 < \mu)$ ، $(M1 < M2 < -\mu)$، $(M1 < -\mu < M2)$ ، $(-\mu < M1 < M2)$ } .** أيضًا تم تمثيل تأثير علامة وقيمة معامل كتلة الهيجز **μ** على إجمالي المقاطع النووية العرضية فى حالة كل من الهجزينو و الجيجينو .