Kontribusi Fisika Indonesia
Vol. 12 No. 1, Januari 2001

Progress Report On Supersymmetric Particle Searches With the D-Zero Detector

Johannes V. Djoko Wirjawan
Physics Department
Widya Mandala Catholic University
Jl. Kalijudan 37 Surabaya 60114
e-mail : djoko@mail.wima.ac.id

Abstract
Supersymmetry which relates bosons and fermions is a new symmetry theory. Searches for supersymmetric particles at the large colliders around the world that just started in the last two decades show slow progress. Based on accumulated data of about 100 pb^{-1} collected with the D-Zero detector at Fermilab, no evidence of supersymmetric particles was found. Lower mass limits based on the production cross-section and the exclusion of some parameter space for squark-gluino and chargino-neutralino searches will be discussed.

Keywords: *Supersymmetry, Squark-gluino, Chargino-neutralino, D-Zero*

Abstrak
Supersimetri yang menghubungkan boson dan fermion merupakan sebuah teori simetri baru. Pencarian partikel-partikel supersimetri pada collider-collider besar di seluruh dunia yang dimulai sekitar dua dasa warsa terakhir menunjukkan kemajuan yang lambat. Berdasarkan akumulasi data sekitar 100 pb^{-1} yang dikumpulkan dengan detektor D-Zero, belum dapat ditemukan bukti akan adanya partikel-partikel supersimetri. Batas minimum massa partikel yang dicari berdasarkan penampang hamburan proses produksi yang diharapkan dan penentuan ruang parameter yang terlarang untuk menemukan squark-gluino dan chargino-neutralino akan dibahas.

Kata kunci *: Supersymmetry, Squark-gluino, Chargino-neutralino, D-Zero*

1. Introduction

Top quark discovery[1,2] by the Collider Detector at Fermilab (CDF) and the D-Zero (D0) collaborations in 1995 and the direct evidence of the tau neutrino by the Direct Observation of Neutrino Tau (DONUT) collaboration in July 2000 lengthen the list of successes of the standard model (SM). So far there is no single experiment indicating the flaw of the SM. In spite of these facts, most physicists believe that the SM is not the ultimate theory. The main reason is the fine tuning problem due to the existence of quadratic divergence in the radiative corrections to the Higgs boson mass as the internal momentum in the loop becomes very large. One of the favored theories that can solve the fine-tuning problem and keep the good features of the SM is supersymmetry (SUSY)[3]. There is an experimental hint, assuming the existence of SUSY, an extrapolation of the three gauge couplings (strong, electromagnetic, and weak) from the LEP high precision data gives a unification of the couplings[4] around the Grand Unified Theory (GUT) energy scale.

SUSY can be considered as a fundamental space-time symmetry relating bosons and fermions. As a consequence, for every particle in the SM, SUSY predicts the existence of its supersymmetric particle (sparticle) partner that differs in spin by ½ unit. Since SUSY is a space-time symmetry, if it is the symmetry preferred by nature then a particle and its sparticle partner must be identical in all aspects but the spin. The sparticle of electron must be a scalar (spin zero) particle with charge and mass identical to electron. However, there is no such sparticle nor other sparticles of the SM particles ever found. This fact leads to a conclusion, if SUSY is indeed the true symmetry, it must be broken severely. Due to the broken symmetry, a$_n$ SM particle and its sparticle do not necessarily have the same mass.

To be a useful theory, SUSY must be implemented in a realistic model. Although there is no direct evidence, yet, for the existence of SUSY particles, many models based on this symmetry have been developed and sparticle searches have been conducted in many high-energy experiments around the world. Following Wess-Zumino[5], many SUSY models have been developed as an extension of the SM. The most straightforward model is known as the minimal supersymmetric standard model (MSSM). Another SUSY model that includes gravity as well as strong and electroweak interactions is known as minimal supergravity (SUGRA)[6]. While there are a lot of parameters used in MSSM, in the SUGRA model there are only five parameters used, namely the common scalar mass at GUT scale, m_o, the common fermion mass at GUT scale, $m_{1/2}$, the soft trilinear SUSY breaking term at GUT scale, A_o, the ratio of the vacuum expectation values of the two Higgs doublets at the electroweak scale, tan β, and the sign of the Higgsino mass term, μ. In all SUSY models, a new multiplicative quantum number called R parity is introduced to assign $R = +1$ for every SM particle and $R = -1$ for every sparticle. In most cases R is assumed to be conserved, resulting the existence of the lightest supersymmetric particle (LSP) that is stable. In this analysis the LSP is assumed to participate only in gravitation and weak interactions only. The gravitation is, however, almost always being neglected in the analysis.

The D0 detector[7] consists of three primary systems: a non-magnetic central tracking system, a nearly hermetic uranium-liquid argon calorimeter, and a muon spectrometer. It was designed to be multipurpose, capable of high precision measurements of particle direction, energy, and momentum as well as reliable particle identification necessary for a variety of physics analyses, including new physics beyond the SM such as SUSY. The supersymmetric particle searches with the D0 detector has begun since the early operation of the detector. In this report we only discuss the D0 searches that cover the squark-gluino and chargino-neutralino sectors. Since the detector can only record the final products of collisions occur in the detector, the searches are characterized by the final states of the expected interactions.

2. Squark and Gluino Searches

Squarks and gluinos might be produced through strong interaction at the Tevatron. The production cross sections may be large and depend only on the masses of the squarks and gluinos themselves. High energy collisions of the protons and antiprotons at the Tevatron actually involve individual quarks and gluons within the proton and antiproton. Assuming R-parity conservation, squarks and gluinos are always produced in association or in pairs. Soon after being produced squarks and gluinos undergo direct or cascade decays. The direct decays of squarks and gluinos will produce very energetic jets and LSPs without going through intermediate gauginos, while cascade decays of squarks and gluinos will produce more softer jets, LSPs, and probably leptons or photons. Weakly interacting LSPs are not directly observed in events, but their existence and energy can be inferred from the missing transverse energy, $\not{E}_T$, in the events. The search for squarks and gluinos in this report include several final states: jets + $\not{E}_T$, $\gamma \not{E}_T$ + jets, ee $\not{E}_T$ + jets.

In the jets + $\not{E}_T$ final states for the squarks and gluinos search[8], top squark was excluded from the analysis due to its mass that might be much lighter than the other squarks masses. Candidate events in this analysis must have at least three jets with transverse energy, $E_T > 25$ GeV (the leading jet has $E_T > 115$ GeV), $\not{E}_T > 100$ GeV, and scalar sum of the jet E_T in the event but excluding the leading jet, $H_T > 150$ GeV. Based on 79,2 pb^{-1} integrated luminosity of data, there were 3 events satisfying those requirements. This number of candidates is consistent with the expected number of the SM background dominated by the $t\bar{t} \rightarrow X$ and QCD processes. Since no events were observed in excess of the SM background prediction, limits in the $m_o - m_{1/2}$ parameter space of minimal SUGRA models are calculated for fixed parameters tan β = 2, $A_o = 0$, and $\mu < 0$. The excluded regions includes all minimal SUGRA models with squark mass, $m_{\tilde{q}} < 250$ GeV/c^2. For small m_o, gluinos with mass less than 300 GeV/c^2 are excluded and if the squarks and gluinos have the same mass, the common mass must be greater than 260 GeV/c^2. A parallel search focused on the light top squark pair productions[9] subsequently decaying into two acollinear energetic jets with significant $\not{E}_T$ was also pursued. Requiring $\not{E}_T > 40$ GeV, at least two jets with $E_T > 30$ GeV not be back-to-back in the azimuthal angle ϕ, and rejecting leptons with $E_T > 10$ GeV on 7.4 pb^{-1} integrated luminosity of data, we observed 3 candidate events. This number, however, is consistent with the predicted SM background dominated by W and Z background, (3,5 ± 1,2) events. Given no observed excess of events above the expected background we set an exclusion region in the stop – LSP mass ($m_{\tilde{t}_1}$ - $m_{\tilde{\chi}_1^o}$) parameter space. The maximum excluded value for $m_{\tilde{t}_1}$ = 93 GeV/c^2 for $m_{\tilde{\chi}_1^o}$ = 8 GeV/c, while the maximum excluded value for $m_{\tilde{\chi}_1^o}$ = 44 GeV/c^2 for $m_{\tilde{t}_1}$ = 85 GeV/c^2.

In the $\gamma \not{E}_T$ + jets analysis[10], candidate events must have at least one photon with E_T^{γ} >

20 GeV, two or more jets, each with E_T^j > 20 GeV, and $\not{E}_T$ > 25 GeV. Based on 99.4 pb^{-1} integrated luminosity of data, 318 events satisfy those requirements. The expected SM background, dominated by QCD processes, is 320 ± 30 events. Varying the offline cuts to improve the signal to background ratio shows that the number of the observed events is always consistent with the predicted SM background. Within the MSSM, with choices of parameters consistent with 100% branching fraction of the second lightest neutralino, $\tilde{\chi}_2^o$ decays into a photon (γ) + LSP ($\tilde{\chi}_1^o$) and $m_{\tilde{\chi}_2^o} - m_{\tilde{\chi}_1^o}$ > 20 GeV/c^2, we obtain a lower mass limit of 310 GeV/c^2 for equal mass squarks and gluinos and of 240 GeV/c^2 for squarks (gluinos) when gluinos (squarks) are heavy.

In the ee $\not{E}_T$ + jets analysis[11], we only consider the top squark pair production, each top squark decays into the lightest chargino, $\tilde{\chi}_1^{\pm}$ and a b quark, then subsequently $\tilde{\chi}_1^{\pm}$ decays into a lepton and an LSP ($\tilde{\chi}_1^o$). Candidate events in this analysis must have at least one jet with E_T^j > 30 GeV, two electrons with E_T^{e1} > 16 GeV, E_T^{e2} > 8 GeV, and $\not{E}_T$ > 22 GeV. Additional requirements on the di-electron invariant mass, m_{ee} < 60 GeV/c^2 to remove $Z \to ee$ events and on $E_T^{sum} = E_T^{e1} + E_T^{e2} + \not{E}_T$ < 90 GeV. Based on 74,9 pb^{-1} integrated luminosity, 2 events satisfy those requirements. The predicted SM background, dominated by jets misidentified as electrons and $Z \to \tau\tau \to ee$, is 4.4 ± 0.8 events. Given no observed excess of events above the expected background we set an upper limit on the cross section times branching fraction, σ·*B*, that is much higher than the predicted σ·*B*. No lower mass limit can be set from this analysis.

3. Chargino and Neutralino Searches

Chargino and neutralino might be produced in associations or in pairs from the very energetic proton antiproton collisions at the Tevatron. The searches in this sector consists of two different final states: trilepton + $\not{E}_T$ and diphoton + $\not{E}_T$.

In the trilepton analysis[12], the lightest chargino, $\tilde{\chi}_1^{\pm}$, and the second lightest neutralino, $\tilde{\chi}_2^o$, are assumed to be produced in association through virtual (off-shell) *W* from a quark anti quark collision. Assuming the lightest neutralino, $\tilde{\chi}_1^o$, is the LSP, both chargino and neutralino will subsequently decay into leptons and LSPs make up the trilepton and $\not{E}_T$ final states. Considering only charged leptons (electron and muon), the trilepton analysis actually consists of four final states: $eee + \not{E}_T$, $ee\mu + \not{E}_T$, $e\mu\mu + \not{E}_T$, and $\mu\mu\mu + \not{E}_T$. This analysis is often considered as golden channel due to the minimum SM background.

Candidate events are required to have three isolated leptons, at least with E_T > 5 GeV and $\not{E}_T$ > 10 GeV. After removing events with di-electron invariant mass 81-106 GeV/c^2 and back-to-back dileptons to reduce $Z \to \ell\bar{\ell}$ events and removing events with invariant mass 5 GeV/c^2 to reduce J/ψ events, we observed no candidate event in all four channels with integrated luminosity ranges from 82.7 pb^{-1} in $\mu\mu\mu$ channel to 95.1 pb^{-1} in *eee* channel. This null result can be translated into an upper limit of the cross section of the chargino-neutralino associated production times the branching fraction to any of the trileptonic final states as a function of the chargino mass, $m_{\tilde{\chi}_1^{\mp}}$. This limit ranges from 0.7 *pb* for $m_{\tilde{\chi}_1^{\mp}}$ = 45 GeV/c^2 to 0.1 *pb* for $m_{\tilde{\chi}_1^{\mp}}$ = 124 GeV/c^2.

In the diphoton analysis[13], $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^o$ are produced in pairs. Assuming that the LSP is gravitino, $\tilde{G}$, and $\tilde{\chi}_1^o$ is the next lightest supersymmetric particle (NLSP), then $\tilde{\chi}_1^o$ will decay with 100% branching fraction into $\gamma\tilde{G}$. Thus, pair production of charginos and neutralinos yields $\gamma\gamma\not{E}_T$ events with high transverse energy (E_T) and large missing transverse energy ($\not{E}_T$), with or without jets. Candidate events in this analysis must have two photons with $E_T^{\gamma1}$ > 20 GeV and $E_T^{\gamma2}$ > 12 GeV, and $\not{E}_T$ > 25 GeV. Based on 106.3 pb^{-1} integrated luminosity, 2 candidate events were observed. The expected SM background is 2.3 ± 0.9 events, dominated by QCD with misidentified photons and/or mismeasured $\not{E}_T$. Interpretation of this result in the MSSM framework with light gravitino can be translated in the exclusion of the chargino masses below 137 GeV/c^2.

4. Conclusion

We have searched supersymmetric particles in the squark-gluino and chargino-neutralino sectors through various final states, but we have not seen any compelling evidence for the existence of supersymmetric particles. Given no observed excess events over the predicted SM background, some significant parameter space region has been excluded, lower mass limits on some sparticles, depending on the model assumed, are set. At this time the upgrade of the D0 detector is in progress to anticipate with higher luminosity in the coming run. With the expected several order of higher accumulated data in the coming run, if supersymmetric particles still can not be found at the Tevatron then we might have to wait until the Large Hadronic Collider (LHC) starts its operation. If still sparticles are not found at the LHC, then most likely SUSY is not the correct theory, no matter how beautifull it is.

Acknowledegments

We thank the staffs at Fermilab and collaborating institutions for their contributions to this work and acknowledge support from the Department of Energy and National Science Foundation (U.S.A), Commissariat à L'Energie Atomique (France), Ministries for Atomic Energy and Science and Technology Policy (Russia), CNPq (Brazil), Departments of Atomic Energy and Science and Education (India), Colciencias (Columbia), CONACyT(Mexico), Ministry of Education and KOSEF (Korea), CONICET and UBACyT (Argentina), and the A.P. Sloan Foundation.

References

1. CDF Collaboration, F. Abe *et al.* Phys. Rev. Lett. 74, 2632 (1995).
2. D0 Collaboration, S. Abachi *et al.* Phys. Rev. Lett. 74, 2632 (1995).
3. Y.A. Golfand and E.S. Likhtman, JETP Lett. 13, 323 (1971)
   D.V. Volkov and V.P. Akulov, Phys. Lett. B 46, 109 (1973).
4. P. Langacker and M. Luo, Phys. Rev. D44, 817 (1991)
   J. Ellis, S. Kelley and D.V. Nanopoulos, Phys. Lett. B249, 441 (1990)
   U. Amaldi, W. de Boer and H. Furstenau, Phys. Lett. B260, 447 (1991)
5. J. Wess and B. Zumino, Nucl. Phys. B70, 139 (1974)
   J. Wess and B. Zumino, Phys. Lett. B 49, 52 (1974).
6. A. Chamseddine, R. Arnowitt, and P. Nath, Phys. Rev. Lett. 49, 970 (1982)
   R. Barbieri, S. Ferrara, and C. Savoy, Phys. Lett. B119, 343 (1982)
   L.J. Hall, J. Lykken, and S. Weinberg, Phys. Rev. D27, 2359 (1983)
   H. Baer, C. Kao, and X. Tata, Phys. Rev. D48, 2978 (1993).
7. D0 Collaboration, S. Abachi *et al*., Nucl. Instrum. Methods Phys. Res., Sect. A 338, 185 (1994).
8. D0 Collaboration, B. Abbott et al., Phys. Rev. Lett. 83, 4937 (1999).
9. D0 Collaboration, S. Abachi et al., Phys. Rev. Lett. 76, 2222 (1996).
10. D0 Collaboration, S. Abbott et al., Phys. Rev. Lett. 82, 29 (1999)
11. D0 Collaboration, S. Abachi et al., Phys. Rev. D57, 589 (1998).
12. D0 Collaboration, S. Abbott et al., Phys. Rev. Lett. 80, 1591 (1998).
    J.V.D. Wirjawan, Ph.D. thesis, Texas A&M University, College Station, 1997 (unpublished).
13. D0 Collaboration, S. Abbott et al., Phys. Rev. Lett. 80, 442 (1998).