# Supersymmetric Analysis and Predictions Based on the Collider Detector at Fermilab $ee\gamma\gamma$ + Missing Energy Event

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(Received 14 February 1996)

We have analyzed the Collider Detector at Fermilab $ee\gamma\gamma$ + missing energy event. Its kinematics and expected rate are consistent with selectron pair production. We consider two classes of general low-energy supersymmetric theories where the lightest neutralino or the gravitino is the lightest supersymmetric particle. The supersymmetric Lagrangian is tightly constrained by the production and decay of the selectron and other data. We discuss other processes at the Fermilab Tevatron and at LEP that could confirm or exclude a supersymmetric explanation of the event. [S0031-9007(96)00051-8]

PACS numbers: 14.80.Ly, 12.60.Jv, 13.85.Qk

The CDF Collaboration at the Fermilab Tevatron collider has reported [1] an $ee\gamma\gamma + \not{E}_T$ event that does not seem to have a standard model (SM) interpretation. The event has two isolated electrons and two isolated photons, all with large transverse energy $E_T \sim 30$–$60$ GeV and missing energy $\not{E}_T \simeq 53$ GeV with little hadronic energy throughout the detector. We confirm that the event is consistent with the rate and kinematics of selectron pair production ($p\overline{p} \rightarrow \tilde{e}^+\tilde{e}^-$), with a mass $m_{\tilde{e}}$ in the range 80 to 130 GeV, and about the expected cross section for one event in 100 $\text{pb}^{-1}$ of data. If the lightest supersymmetric particle (LSP) is the neutralino ("neutralino LSP" scenario), then the selectron $\tilde{e}$ must decay mainly into the next-to-lightest neutralino $\tilde{\chi}_2^0$ and an electron ($\tilde{e} \rightarrow \tilde{\chi}_2^0 e$), followed by $\tilde{\chi}_2^0$ decay to the lightest neutralino $\tilde{\chi}_1^0$ through the radiative channel $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\gamma$ [2,3]; this chain will have a high probability if $\tilde{\chi}_1^0$ is Higgsinolike while $\tilde{\chi}_2^0$ is gauginolike. Alternatively, if there is a very light gravitino $\tilde{G}$ [4] with a mass $m_{\tilde{G}} < 1$ keV ("light gravitino" scenario), then the selectron decay is interpreted as $\tilde{e} \rightarrow \tilde{\chi}_1^0 e$ followed by $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$. While we were writing this paper, Ref. [5] appeared. It also discusses the light gravitino scenario, but not the neutralino LSP scenario, for the CDF $ee\gamma\gamma + \not{E}_T$ event.

In the SM, the most likely explanation for the $ee\gamma\gamma + \not{E}_T$ event is $WW\gamma\gamma$ production [1]. We have estimated (using MADGRAPH helicity amplitudes, checked with photon emission estimates) the cross section for $ee\gamma\gamma$ to be roughly 0.006 fb, including $W \rightarrow e\nu_e$ branching ratios, and $E_T^\gamma > 10$ GeV, $|\eta^\gamma| < 1$, giving less than $10^{-3}$ events expected with the current CDF data. We estimate the background for $WW\gamma g$ with $g$ faking a $\gamma$ to be even smaller.

We determine a set of supersymmetric soft-breaking parameters, superpotential parameters, and $\tan\beta$ values that give masses and event rates consistent with the $ee\gamma\gamma + \not{E}_T$ event, as well as all other theoretical and phenomenological constraints, including LEP1–1.3 data. Then we calculate rates for production and decay of selectrons, charginos, neutralinos, and associated processes. Finding any of these associated events would greatly strengthen the supersymmetric interpretation.

We illustrate how to experimentally distinguish the two supersymmetric scenarios which we consider. When $\tilde{\chi}_1^0$ is the LSP, we find the soft-breaking masses $M_1$, $M_2$ do not satisfy the gaugino mass unification condition $M_1 \simeq 5/3 \tan^2\theta_W M_2$, but rather $M_1 \simeq M_2$. In the light gravitino scenario, one can maintain the gaugino mass unification relation. Our main result is to establish the validity of the supersymmetric interpretation of the $ee\gamma\gamma + \not{E}_T$ event by identifying the region of parameter space that satisfies the kinematic, cross section, and branching ratio constraints. Then we provide predictions for events whose presence (absence) would confirm (exclude) the supersymmetric interpretation of the $ee\gamma\gamma + \not{E}_T$ event.

The minimal supersymmetric standard model (MSSM) has a particle spectrum including the SM particles plus their superpartners, with the SM gauge group $\mathrm{SU}(3)_c \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$. We generally follow the notation and conventions of Ref. [6], including the sign of $\mu$. We perform our analysis in terms of a general supersymmetric Lagrangian at the electroweak scale, with no unification assumptions or significant assumptions about the unknown superpartner masses. In low-energy supersymmetry, as in the SM, masses are unknown until they are measured. Some cross sections depend only on the mass of the produced particles and are thus unique, while others depend on masses of exchanged sparticles and can have a range, which we report. Different sets of supersymmetric mass and coupling parameters are often referred to as "models," though they all parametrize the same Lagrangian.

Assume the $ee\gamma\gamma + \not{E}_T$ event can be ascribed to selectron pair production $q\overline{q} \rightarrow Z^*, \gamma^* \rightarrow \tilde{e}^+\tilde{e}^-$ with a subsequent 2-body decay for each selectron. We use $\tilde{X}_1$, $\tilde{X}_2$ for the lightest and next-to-lightest neutral, odd $R$-parity, fermion corresponding to $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ in the neutralino LSP scenario and $\tilde{G}$, $\tilde{\chi}_1^0$ in the light gravitino scenario, respectively. If all decays occur close to the apparent vertex, we can find some nontrivial constraints. We vary the two missing momentum 4-vectors associated with $\tilde{X}_1$, subject to the constraints of equality of selectron, $\tilde{X}_2$ and $\tilde{X}_1$ masses in the two decays and conservation of total transverse momentum. This generates a solution space with constrained ranges for $m_{\tilde{e}}$, $m_{\tilde{X}_2}$, and $m_{\tilde{X}_1}$. Only one pairing of electron and photon gives consistent kinematics for $m_{\tilde{e}} \lesssim 130$ GeV. Also, $m_{\tilde{e}} > 80$ GeV, $38 \text{ GeV} \lesssim m_{\tilde{X}_2} \lesssim \min[1.12 m_{\tilde{e}} - 37 \text{ GeV}, 95 \text{ GeV} + 0.17 m_{\tilde{X}_1}]$, $m_{\tilde{X}_1} \lesssim \min[1.4 m_{\tilde{e}} - 105 \text{ GeV}, 1.6 m_{\tilde{X}_2} - 60 \text{ GeV}]$, and $m_{\tilde{e}^+\tilde{e}^-} \gtrsim 275$ GeV. These constraints are based on measured quantities that have experimental errors so all our numbers have associated errors, and can be sharpened with a more detailed study of the event. Further constraints arise in particular interpretations described below. (In principle, the event could also be chargino pair production, but this is disfavored by both dynamical and kinematical considerations; we will discuss this in Ref. [7].)

In Fig. 1, we display the cross sections for slepton production [8,9] at the Fermilab Tevatron ($\sqrt{s} = 1.8$ TeV) in the mass region suggested by the kinematics. Typically $\sigma(\tilde{e}_L\tilde{e}_L) \approx 2.3\sigma(\tilde{e}_R\tilde{e}_R)$ for equal mass sleptons. If the $ee\gamma\gamma + \not{E}_T$ event is from $\tilde{e}_L$ production, then the $\tilde{e}_L\tilde{\nu}_e$ channel is definitely accessible since $\tilde{e}_L$ and $\tilde{\nu}_e$ are in an $SU(2)_L$ doublet and are thus related by the sum rule $m_{\tilde{e}_L}^2 = m_{\tilde{\nu}_e}^2 + M_W^2|\cos 2\beta|$, with $\tan\beta > 1$; hence $m_{\tilde{\nu}_e} < m_{\tilde{e}_L}$. If the event is from $\tilde{e}_R$ production, then $m_{\tilde{e}_L}$ and $m_{\tilde{\nu}_e}$ are not determined by the event.

In the neutralino LSP scenario, the decay $\tilde{e} \to \tilde{\chi}_2^0 e$ must dominate, hence $\tilde{\chi}_2^0$ is largely gaugino (i.e., $\tilde{\gamma}$, $\tilde{Z}$ rather than Higgsino). In order to have the radiative decay $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\gamma$ dominate, it is necessary to have one of $\tilde{\chi}_1^0, \tilde{\chi}_2^0$ be mainly gaugino and the other mainly Higgsino [2,3]. Since only the gaugino will couple to $\tilde{e}e$, this uniquely fixes $\tilde{\chi}_1^0$ to be mainly Higgsino, $\tilde{\chi}_2^0$ to be mainly gaugino. An examination of the neutralino mass matrix [10] then leads to the region of parameter space $\tan\beta \simeq 1$ and $M_1 \simeq M_2$. In the limit when these relations are exact, one neutralino is a pure Higgsino $\tilde{\chi}_1^0 \simeq \tilde{H}_b^0$ (the "symmetric combination" of $\tilde{H}_1^0$ and $\tilde{H}_2^0$) with a mass $|\mu|$, and another is a pure photino with a mass $M_1 = M_2$. The other two neutralino states are $Z$-ino–Higgsino mixtures with masses $\frac{1}{2}|M_2 + \mu \pm \sqrt{(M_2 - \mu)^2 + 4M_Z^2}|$. The two chargino masses are given by the same relation with $M_Z \to M_W$. In order to obtain the desired hierarchy of neutralino masses, $\mu$ must be negative, and $|\mu|$ must be smaller than $M_1 \simeq M_2$. Also, the kinematics of the event give $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} \gtrsim 30$ GeV, and $m_{\tilde{\chi}_1^\pm}$, $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_3^0}$ must be sufficiently heavy to not have $\tilde{\chi}_1^+\tilde{\chi}_1^-$ and $\tilde{\chi}_1^0\tilde{\chi}_3^0$ pairs seen at LEP1.3. This almost fixes the allowed ranges of $|\mu|$ and $M_1 \simeq M_2$.

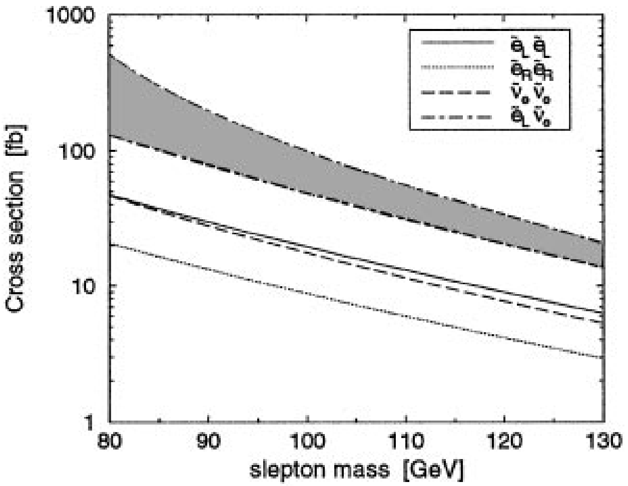

FIG. 1. Cross sections for $\tilde{e}_L\tilde{e}_L$, $\tilde{e}_R\tilde{e}_R$, $\tilde{\nu}_e\tilde{\nu}_e$, and $\tilde{e}_L\tilde{\nu}_e$ production at the Tevatron for $\sqrt{s} = 1.8$ TeV versus $m_{\tilde{e}_L}$, $m_{\tilde{e}_R}$, $m_{\tilde{\nu}_e}$, and $m_{\tilde{e}_L}$, respectively. The cross sections depend only on the masses of the sleptons; the shaded band for $\tilde{e}_L\tilde{\nu}_e$ corresponds to the allowed range of $m_{\tilde{\nu}_e}$ for a fixed $m_{\tilde{e}_L}$ that can be parametrized by $\tan\beta$. The lower (upper) dot-dashed line corresponds to $\tan\beta = 1$ (3).

If we try to move away from $M_1 \simeq M_2$ (toward gaugino mass unification), it is still possible to have a large $B(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\gamma)$ when $M_1 \simeq M_2/2 \simeq -\mu$ ($\mu < 0$) and small $\tan\beta$ [3], but then $m_{\tilde{\chi}_2^0}$ is near $m_{\tilde{\chi}_1^0}$ and the kinematical properties of the event cannot be satisfied; if one increases the mass difference by increasing $\tan\beta$, the radiative branching ratio drops. Thus it appears to be very difficult, if not impossible, to have an interpretation of the $ee\gamma\gamma + \not{E}_T$ event with gaugino mass unification.

The analytical limits discussed above point to a specific region of the supersymmetric parameter space that we have explored with complete numerical calculations. The inputs include $M_1$, $M_2$, $\mu$, $\tan\beta$ to obtain the chargino and neutralino masses and mixings, in addition to the squark and slepton sector, which enter the branching ratios. Apart from a possibly light stop $\tilde{t}_1$ ($\tilde{t}_1$ is the lightest stop mass eigenstate obtained from a linear combination of the stop weak eigenstates $\tilde{t}_L$ and $\tilde{t}_R$ [6]), squarks do not significantly affect our analysis as long as they are heavier than about 200 GeV. In our numerical calculations we assume all squarks are heavier than 200 GeV (the effect of light squarks will be more fully discussed in Ref. [7]). The LEP1 limit on the mass of the lightest neutral Higgs boson $h$ is sufficient to ensure $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\gamma$ and not $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h$. For each set of supersymmetric parameters (each allowed "model") we calculate cross sections for chargino, neutralino, and chargino-neutralino pair production at LEP and Tevatron, as well as the branching ratios of all charginos, neutralinos, and sleptons for every allowed channel. The final set of $ee\gamma\gamma + \not{E}_T$ event constraints on the neutralino LSP scenario is given in Table I.

There are a number of processes that must occur if the neutralino LSP interpretation is valid. The $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ cross section at the 1.8 TeV Tevatron collider can be found by varying $M_1$, $M_2$, $\mu$, $\tan\beta$ (plus $m_{\tilde{u}_L}$, $m_{\tilde{d}_L}$) through the allowed ranges defined by the $ee\gamma\gamma + \not{E}_T$ event. $\sigma(\tilde{\chi}_1^\mp\tilde{\chi}_2^0)$

TABLE I. Constraints on the MSSM parameters and masses in the neutralino LSP scenario requiring the total branching ratio $B[\tilde{e}^+\tilde{e}^- \rightarrow e^+e^-\tilde{\chi}_2^0(\rightarrow \gamma\tilde{\chi}_1^0)\tilde{\chi}_2^0(\rightarrow \gamma\tilde{\chi}_1^0)] > 50\%$ and the $\sigma(\tilde{e}\tilde{e}) \times B > 4$ fb for $\tilde{e} = \tilde{e}_L$ and $\tilde{e} = \tilde{e}_R$.

| $ee\gamma\gamma + \not{E}_T$ Constraints on Supersymmetric Parameters | |
|---|---|
| $\tilde{e}_L$ | $\tilde{e}_R$ |
| $100 \lesssim m_{\tilde{e}_L} \lesssim 130$ GeV | $100 \lesssim m_{\tilde{e}_R} \lesssim 112$ GeV |
| $50 \lesssim M_1 \lesssim 92$ GeV | $60 \lesssim M_1 \lesssim 85$ GeV |
| $50 \lesssim M_2 \lesssim 105$ GeV | $40 \lesssim M_2 \lesssim 85$ GeV |
| $0.75 \lesssim M_2/M_1 \lesssim 1.6$ | $0.6 \lesssim M_2/M_1 \lesssim 1.15$ |
| $-65 \lesssim \mu \lesssim -35$ GeV | $-60 \lesssim \mu \lesssim -35$ GeV |
| $0.5 \lesssim \lvert\mu\rvert/M_1 \lesssim 0.95$ | $0.5 \lesssim \lvert\mu\rvert/M_1 \lesssim 0.8$ |
| $1 \lesssim \tan\beta \lesssim 3$ | $1 \lesssim \tan\beta \lesssim 2.2$ |
| $33 \lesssim m_{\tilde{\chi}_1^0} \lesssim 55$ GeV | $32 \lesssim m_{\tilde{\chi}_1^0} \lesssim 50$ GeV |
| $58 \lesssim m_{\tilde{\chi}_2^0} \lesssim 95$ GeV | $60 \lesssim m_{\tilde{\chi}_2^0} \lesssim 85$ GeV |
| $88 \lesssim m_{\tilde{\chi}_3^0} \lesssim 105$ GeV | $88 \lesssim m_{\tilde{\chi}_3^0} \lesssim 108$ GeV |
| $110 \lesssim m_{\tilde{\chi}_4^0} \lesssim 145$ GeV | $110 \lesssim m_{\tilde{\chi}_4^0} \lesssim 132$ GeV |
| $62 \lesssim m_{\tilde{\chi}_1^\pm} \leq 95$ GeV | $65 \lesssim m_{\tilde{\chi}_1^\pm} \leq 90$ GeV |
| $100 \lesssim m_{\tilde{\chi}_2^\pm} \leq 150$ GeV | $100 \lesssim m_{\tilde{\chi}_2^\pm} \leq 125$ GeV |

ranges from 100 to 1000 fb for $m_{\tilde{\chi}_2^0} \approx 60$ GeV, with the range decreasing to about 20 to 100 fb for $m_{\tilde{\chi}_2^0} \approx 90$ GeV. It gives events such as $\tilde{\chi}_1^\pm(\rightarrow l^\pm\nu\tilde{\chi}_1^0)\tilde{\chi}_2^0(\rightarrow \gamma\tilde{\chi}_1^0)$ with a signature $l^\pm\gamma\not{E}_T$, $\tilde{\chi}_1^\pm(\rightarrow q\bar{q}'\tilde{\chi}_1^0)\tilde{\chi}_2^0(\rightarrow \gamma\tilde{\chi}_1^0)$ with a signature $jj\gamma\not{E}_T$, or $\tilde{\chi}_1^\pm(\rightarrow \tilde{t}_1 b)\tilde{\chi}_2^0(\rightarrow \gamma\tilde{\chi}_1^0)$ followed by $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ with signature $\gamma bc\not{E}_T$. The channel $\tilde{e}_L\tilde{\nu}_e$ gives typically $\tilde{e}_L(\rightarrow e\tilde{\chi}_2^0)\tilde{\nu}_e(\rightarrow \nu_e\tilde{\chi}_2^0)$ followed by $\tilde{\chi}_2^0 \rightarrow \gamma\tilde{\chi}_1^0$ with a signature $e\gamma\gamma\not{E}_T$ ($\tilde{\nu}_e \rightarrow e\tilde{\chi}_1^\pm$ and $\tilde{\nu}_e \rightarrow \nu_e\tilde{\chi}_1^0$ are suppressed because the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ are Higgsinolike). The $\tilde{\nu}_e\tilde{\nu}_e$ channel gives $\gamma\gamma\not{E}_T$, as does $\tilde{\chi}_2^0\tilde{\chi}_2^0$ production.

We now turn to the alternative light gravitino interpretation of the event. It was originally pointed out by Fayet [4] that the gravitino can have couplings to (gauge boson, gaugino) and (scalar, chiral fermion) which are inversely proportional to the gravitino mass and so can affect collider phenomenology [4,11–13]. More recently, there has been theoretical impetus for the light gravitino coming from considerations of dynamical supersymmetry breaking [14].

One major point in favor of the light gravitino scenario is that the kinematics with $m_{\tilde{G}} = m_{\tilde{\chi}_1} \approx 0$ allows the selectron to be as light as 80 GeV, with a correspondingly larger production cross section, and the branching fraction should be essentially 100%, with no other adjustment of parameters. Supersymmetric signatures will often include two hard photons plus missing energy. If $\Gamma(\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma)$ is too small, $\tilde{\chi}_1^0$ will decay outside the detector, and the signature for any given event would be the same as in the usual MSSM. In terms of its energy, the decay distance of $\tilde{\chi}_1^0$ is given by

$$d = 1.76 \times 10^7 \kappa_1^{-1}(E_{\tilde{\chi}_1^0}^2/m_{\tilde{\chi}_1^0}^2 - 1)^{1/2} m_{\tilde{G}}^2 m_{\tilde{\chi}_1^0}^{-5}\ \text{cm},$$

where $\kappa_i = \lvert\sin\theta_W N_{i2} + \cos\theta_W N_{i1}\rvert^2$ in the notation of [6], $m_{\tilde{G}}$ is measured in eV, and $m_{\tilde{\chi}_1^0}$ in GeV. By requiring $d \lesssim 150$ cm, we find a very rough upper limit of 250 eV on the gravitino mass. If $m_{\tilde{G}} \gtrsim (5, 50)$ eV for $m_{\tilde{\chi}_1^0} = (40, 100)$ GeV, the kinematic analysis described earlier is not valid in detail, since the $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ decay length is significant on the scale of the CDF detector.

The light gravitino interpretation suggests several other signatures which can be searched for at the Tevatron and LEP-2. The possibilities include $\tilde{\chi}_1^0\tilde{G}$ and $\tilde{\chi}_2^0\tilde{G}$ production, leading to signatures $\gamma\not{E}_T$ and $\gamma l^+l^-\not{E}_T$ or $\gamma jj\not{E}_T$, respectively. At hadron colliders, one can have $\tilde{g}\tilde{G}$ [12] production, then $\tilde{g}$ can decay dominantly into $g + \tilde{G}$ with a monojet signature. Another possibility is $\tilde{\chi}_1^\pm\tilde{G}$ production with the signature $l^\pm\gamma\not{E}_T$ or $\gamma jj\not{E}_T$.

Other signals which can occur at either the Tevatron or LEP-2 should contain two energetic photons (assuming that one takes the $ee\gamma\gamma + \not{E}_T$ event as establishing that $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ occurs within the detector at least a large fraction of the time). $\tilde{\chi}_1^0\tilde{\chi}_1^0$ or $\tilde{\nu}\tilde{\nu}$ give a $\gamma\gamma\not{E}_T$ signature. The signal $l^\pm\gamma\gamma\not{E}_T$ can occur from either $\tilde{l}_L^\pm\tilde{\nu}$ or $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$ production. The $\tilde{\nu}_e\tilde{\nu}_e$ and $\tilde{e}_L\tilde{\nu}_e$ modes are unavoidable if the $ee\gamma\gamma + \not{E}_T$ event is due to $\tilde{e}_L$ pair production. One also has $\gamma\gamma jj\not{E}_T$ from either $\tilde{\chi}_1^0\tilde{\chi}_2^0$ or $\tilde{\chi}_1^0\tilde{\chi}_1^\pm$ production. Another possible discovery signature is $l^+l^-l'^\pm\gamma\gamma\not{E}_T$ following from either $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ or $\tilde{l}_L^\pm\tilde{\nu}$ production. In general, one can search for any of the usual supersymmetric signatures with an additional pair of energetic photons (one from each $\tilde{\chi}_1^0$ decay). If $\tilde{g}\tilde{g}$ is accessible, it can lead to the usual multijet $+\not{E}_T$ signal, but with two energetic photons. If a stop is light, another possibility is the production of $\tilde{\chi}_1^\pm(\rightarrow \tilde{t}_1 b) + \tilde{\chi}_1^0(\rightarrow \tilde{G}\gamma)$, followed by $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0(\rightarrow \tilde{G}\gamma)$, that gives a signature $bc\gamma\gamma\not{E}_T$ at the Tevatron and does not seem to have a counterpart for the neutralino LSP scenario. Each of the signatures listed above can occur also with only one hard photon if $d$ is comparable to the size of the detector, allowing one of the two decays $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ to be missed. While the neutralino LSP interpretation and the light gravitino interpretation both predict signatures with two energetic photons and $\not{E}_T$, the rates and kinematics will be different and so may eventually be used to distinguish them. Furthermore, if $m_{\tilde{G}}$ is in the upper part of the range favored by dynamical supersymmetry breaking [14], it is not unlikely that the decay length $d$ can eventually be measured in the detector. While we were preparing this paper, two papers [5,15] have appeared which discuss light gravitino signals, inspired by dynamical supersymmetry breaking.

LEP1 only weakly constrains the light gravitino scenario for $m_{\tilde{G}} \ll 1$ eV. In contrast, stronger constraints can be placed on the neutralino LSP scenario from the nonobservation of supersymmetric events at LEP1–1.3. In particular, we require $\sigma(e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_3^0) < 2$ pb (after an evaluation of the initial-state radiation effects) leading to a very small (less than 10) total number of $\tilde{\chi}_1^0\tilde{\chi}_3^0$ events expected in the data of an ideal LEP1.3 "hermetic" detector. Further, about 20% of these events are invisible because of the $\tilde{\chi}_3^0 \rightarrow \nu\bar{\nu}\tilde{\chi}_1^0$ branching ratio.

In the following, we discuss two future phases of LEP with energies $\sqrt{s} = 160$, 190 GeV and an expected integrated luminosity of about 10, 500 $\mathrm{pb}^{-1}$, respectively. The larger integrated luminosity of LEP190 should provide clear and visible supersymmetric signals from light neutralinos and charginos. The most promising channels are $\tilde{\chi}_1^0\tilde{\chi}_3^0$ and $\tilde{\chi}_1^+\tilde{\chi}_1^-$ production. The cross section for $\tilde{\chi}_1^0\tilde{\chi}_3^0$ production is in general below 2 pb at LEP160 and might not be large enough for detection, while LEP190 should be able to disentangle this supersymmetric signal ($\sigma \approx 1$–1.5 pb) from the background. For $\tilde{\chi}_1^+\tilde{\chi}_1^-$ production, the cross section depends on the sneutrino exchange contribution, interfering destructively with the $Z$ exchange. If the $ee\gamma\gamma + \not{E}_T$ event is a result of $\tilde{e}_R^+\tilde{e}_R^-$ production, then the sneutrino mass is not constrained, hence the cross section is not uniquely determined by the chargino mass. The maximum cross section at LEP160 is about 5 pb, but chargino masses may be above threshold. If the $ee\gamma\gamma + \not{E}_T$ event is from $\tilde{e}_L^+\tilde{e}_L^-$, then $m_{\tilde{\nu}_e}$ is fixed by $m_{\tilde{e}_L}$ and the sum rule given previously. Then $\tilde{\chi}_1^+\tilde{\chi}_1^-$ detection is unlikely at LEP160 because the cross section is always below 1.5 pb, since the sneutrino is light. Thus, LEP160 might see superpartners, but the neutralino LSP interpretation of the $ee\gamma\gamma + \not{E}_T$ event cannot be excluded there. LEP190 should detect $\tilde{\chi}_1^0\tilde{\chi}_3^0$ and/or $\tilde{\chi}_1^+\tilde{\chi}_1^-$ (and probably also $\tilde{\chi}_2^0\tilde{\chi}_2^0$) pairs, thus confirming or excluding the neutralino LSP scenario. The main corresponding signatures are "$Z$" + $(\not{E}, \not{p}_T)$, "$WW$" + $\not{E}$ or $b\bar{b}c\bar{c} + \not{E}$, and $\gamma\gamma + \not{E}$.

In conclusion, we have seen that the selectron interpretation of the $ee\gamma\gamma + \not{E}_T$ event can be made in two different supersymmetric scenarios, which ultimately have different sources of supersymmetry breaking. If the event is indeed due to supersymmetry, it strongly constrains the parameter space. The generalized MSSM with a neutralino LSP can accommodate the event if $1 \lesssim \tan\beta \lesssim 3$ and $M_1 \simeq M_2$; gaugino mass unification cannot be satisfied. These constraints do not apply to the light gravitino scenario. It is interesting that in the neutralino LSP scenario both the $ee\gamma\gamma + \not{E}_T$ event and the supersymmetric interpretation of the $Z \rightarrow b\bar{b}$ excess ($R_b$) [16] independently push the parameters into the same region of parameter space, if the lightest stop has a mass in the range 45–80 GeV and if the branching ratio of top into light stop is greater than about 0.45.

It is unnecessary to emphasize the importance of the CDF $ee\gamma\gamma + \not{E}_T$ event if it is indeed from selectron production. It is presently possible to maintain a supersymmetric interpretation even when the event is examined in detail, although of course no interpretation of a single event can be taken too seriously until it is confirmed. We will describe the details of the model building, parameter space constraints, and many aspects of collider predictions for both the neutralino LSP scenario and the light gravitino scenario in a larger paper [7]. Our main goal here is to argue that if the interpretation is correct then a number of other events must occur at the Tevatron, and some at LEP190. If none of these are observed, it would rule out the supersymmetric interpretation of the $ee\gamma\gamma + \not{E}_T$ event as selectron pair production. While some of the signatures can have backgrounds, the combination of one or more hard photons with missing energy implies that the background rates are probably not large. If the confirming events are there, then most other superpartners are being produced at Fermilab, and some will be produced at LEP190. Luminosity at the Tevatron and LEP should lead to the opportunity to detect a number of these important states.

We are grateful for extensive discussions with, and encouragement from, H. Frisch. G. L. K. thanks K. Maeshima and S. Lammel for helpful conversations. We thank T. Sjöstrand for assistance with our background estimate. This work was supported in part by the U.S. Department of Energy. S. A. is supported by an INFN postdoctoral fellowship, Italy.

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