Associated production of a light pseudoscalar Higgs boson with a chargino pair in the NMSSM.

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Abstract

In the next-to-minimal supersymmetric standard model (NMSSM), the unique $\lambda S H_u H_d$ in the superpotential gives rise to a coupling involving the lighter pseudoscalar Higgs boson and a pair of charged or neutral Higgsinos, even in the limit of zero mixing between the two pseudoscalar Higgs bosons. We study the associated production of a very light pseudoscalar Higgs boson with a pair of charginos. The novel signature involves a pair of charged leptons from chargino decays and a pair of photons from the pseudoscalar Higgs boson decay, plus large missing energy at the LHC and ILC. The signal may help us to distinguish the NMSSM from MSSM, provided that the experiment can resolve the two photons from the decay of the pseudoscalar Higgs boson.

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I. INTRODUCTION.

Supersymmetry (SUSY) is one of the best motivated theories beyond the standard model (SM). Not only does it provide a natural solution to the gauge hierarchy problem, but also gives a dynamical mechanism for electroweak symmetry breaking and a natural candidate for dark matter. The most recent lower bound on the Higgs boson mass has been raised to 114.4 GeV [1]. This in fact puts some stress on the soft SUSY parameters, known as the little hierarchy problem, on the minimal supersymmetric standard model (MSSM). Since the Higgs boson receives radiative corrections dominated by the top squark loop, the mass bound requires the top squark mass to be heavier than 1 TeV. From the renormalization-group (RG) equation of $M_{H_u}^2$, the magnitude of $M_{H_u}^2 \sim M_{\tilde{t}}^2 \gtrsim (1000 \text{ GeV})^2$. Thus, the parameters in the Higgs potential are fine-tuned at a level of a few percent in order to obtain a Higgs boson mass of $\mathcal{O}(100)$ GeV.

Such fine-tuning has motivated a number of solutions to relieve the problem. One of these is to add additional singlet fields to the minimal supersymmetric standard model (MSSM). The minimal version of the latter is realized by adding a singlet Higgs field to the MSSM, and becomes the next-to-minimal supersymmetric standard model (NMSSM). It has been shown [2] that in some corners of the parameter space, the Higgs boson can decay into a pair of very light pseudoscalars such that the LEP2 limit can be evaded. It has also been demonstrated that the fine-tuning or the little hierarchy problems are relieved [2]. The NMSSM is in fact well motivated as it provides an elegant solution to the $\mu$ problem in SUSY. The $\mu$ parameter in the term $\mu H_u H_d$ of the superpotential of the MSSM naturally has its value at either $M_{\text{Planck}}$ or zero (due to a symmetry). However, the radiative electroweak symmetry breaking conditions require the $\mu$ parameter to be of the same order as $m_Z$ for fine-tuning reasons. Such a conflict is coined as the $\mu$ problem [3]. In the NMSSM, the $\mu$ term is generated dynamically through the vacuum-expectation-value (VEV), $v_s$, of the scalar component of the additional Higgs field $S$, which is naturally of the order of the SUSY breaking scale. Thus, an effective $\mu$ parameter of the order of the electroweak scale is generated. Explicitly, the superpotential of the NMSSM is given by

$$W = h_u \hat{Q} \hat{H}_u \hat{U}^c - h_d \hat{Q} \hat{H}_d \hat{D}^c - h_e \hat{L} \hat{H}_d \hat{E}^c + \lambda \hat{S} \hat{H}_u \hat{H}_d + \frac{\kappa}{3} \hat{S}^3. \quad (1)$$
It is well-known that the superpotential has a discrete $Z_3$ symmetry, which may induce the harmful domain-wall effect \[4\]. One possible way out is to introduce some nonrenormalizable operators at the Planck scale that break the $Z_3$ symmetry through the harmless tadpoles that they generate \[5\].

Once the domain wall problem is solved, the NMSSM is phenomenologically very interesting. With the additional singlet Higgs field, there are one more CP-even and one more CP-odd Higgs bosons, and one more neutralino other than those in the MSSM. The Higgs phenomenology is much richer \[2, 6, 7, 8\], and so does the neutralinos \[9, 10, 11\]. One particular feature of the NMSSM is the allowable light pseudoscalar boson $A_1$, which is consistent with existing data. Since this $A_1$ mainly comes from the singlet Higgs field, it can escape all the experimental constraints when the mixing angle with the MSSM Higgs fields goes to zero. It was pointed out in Ref. \[2\] that even in the zero mixing limit, there is always a SM-like Higgs boson that decays into a pair of $A_1$’s, which helps the Higgs boson to evade the LEP bound. The possibility to detect such light pseudoscalar Higgs bosons coming from the $H_1$ decay was studied using the two photon mode of the $A_1$, but the two photons may be too collimated for realistic detection \[13\]. Another possibility to detect such an almost decoupling case is to search for the four tau-leptons coming from $h^0 \rightarrow A_1A_1 \rightarrow 4\tau$ decay \[14\]. Nevertheless, in the large $\tan \beta$ and large $\langle v_s \rangle$ limits, the mixing angle is extremely small and approaching zero, such that the decay of $A_1$ into tau-leptons or heavy quarks is negligible.

In this work, we probe another novel signature in the zero-mixing limit. The unique term $\lambda S H_u H_d$ in the superpotential gives rise to the coupling of $\lambda S \tilde{H}_u \tilde{H}_d$, which includes the neutral and charged Higgsinos. We study the associated production of a light pseudoscalar Higgs boson with a chargino pair in the zero-mixing limit at the LHC and ILC. Provided that the pseudoscalar is very light and the mixing angle is less than $10^{-3}$, the dominant decay mode of $A_1$ is a pair of photons. Thus, the novel signature for the production is a pair of charged leptons and a pair of photons plus large missing energy. Such a signal can distinguish NMSSM from the MSSM. We will show the production rates at the LHC and the ILC. One critical issue in identifying the two-photon decay of the light pseudoscalar Higgs boson is whether the two photons can be resolved. We will demonstrate the distribution of the opening angle between the two photons, from which one can tell to what extent the experiments can resolve the two photons. The CMS detector has a “preshower” in the
ECAL that has the strong capability to resolve the two photons of the neutral pion decay as it is the most important background for the intermediate mass Higgs boson search. We can make use of this preshower in the ECAL to resolve the two photons of the $A_1$ decay. We will then show the cross section for the associated production after imposing the preshower requirements. Once we resolve the two photons in the decay of the pseudoscalar Higgs boson, we can differentiate the NMSSM from the MSSM.

The organization is as follows. In the next section, we describe the particular region of parameter space in which the light pseudoscalar Higgs boson decouples and decays into a pair of photons. In Sec. III, we calculate the decay branching ratios of the $A_1$. We then calculate the associated production of the light pseudoscalar Higgs boson with a chargino pair in the zero-mixing limit at the LHC and ILC in Sec. IV. We also work out the distribution of the opening angle of the photon pair. We conclude in Sec. V.

II. ZERO MIXING LIMIT.

The Higgs sector of the NMSSM consists of the usual two Higgs doublets $H_u$ and $H_d$ and an extra Higgs singlet $S$. The extra singlet field is allowed to couple only to the Higgs doublets of the model, the supersymmetrization of which is that the singlet field only couples to the Higgsino doublets. Consequently, the couplings of the singlet $S$ to gauge bosons and fermions will only be manifest via their mixing with the doublet Higgs fields. After the Higgs fields take on the VEV’s and rotating away the Goldstone modes, we are left with a pair charged Higgs bosons, 3 real scalar fields, and 2 pseudoscalar fields. In particular, the mass matrix for the two pseudoscalar Higgs bosons $P_1$ and $P_2$ is

$$V_{\text{pseudo}} = \frac{1}{2} (P_1 \ P_2) \mathcal{M}_P^2 \begin{pmatrix} P_1 \\ P_2 \end{pmatrix},$$

with

$$\mathcal{M}_{P,11}^2 = M_{A}^2,$$
$$\mathcal{M}_{P,12}^2 = \mathcal{M}_{P,21}^2 = \frac{1}{2} \cot \beta_s \left( M_{A}^2 \sin 2\beta - 3\lambda \kappa v_s^2 \right),$$
$$\mathcal{M}_{P,22}^2 = \frac{1}{4} \sin 2\beta \cot^2 \beta_s \left( M_{A}^2 \sin 2\beta + 3\lambda \kappa v_s^2 \right) - \frac{3}{\sqrt{2}} \kappa A_{\kappa} v_s^2.$$
\[ M_A^2 = \frac{\lambda v_s}{\sin 2\beta} \left( \sqrt{2} A_\lambda + \kappa v_s \right), \]  
(4)

and \( \tan \beta = v_u/v_d \) and \( \tan \beta_s = v_s/v \) and \( v^2 = v_u^2 + v_d^2 \). Here \( P_1 \) is the one in MSSM while \( P_2 \) comes from the singlet \( S \) and from the effects of rotating away the Goldstone modes. The pseudoscalar fields are further rotated to the diagonal basis \( (A_1, A_2) \) through a mixing angle [8]:

\[
\begin{pmatrix} A_2 \\ A_1 \end{pmatrix} = \begin{pmatrix} \cos \theta_A & \sin \theta_A \\ -\sin \theta_A & \cos \theta_A \end{pmatrix} \begin{pmatrix} P_1 \\ P_2 \end{pmatrix}
\] 
(5)

where the masses of \( A_i \) are arranged such that \( m_{A_1} < m_{A_2} \). At tree-level the mixing angle is given by

\[
\tan \theta_A = \frac{M_{P12}^2}{M_{P11}^2 - m_{A_1}^2} = \frac{1}{2} \cot \beta_s \frac{M_A^2 \sin 2\beta - 3\lambda \kappa v_s^2}{M_A^2 - m_{A_1}^2}
\] 
(6)

In the approximation of large \( \tan \beta \) and large \( M_A \), which is normally valid in the usual MSSM, the tree-level CP-odd masses can be written as [8]

\[
m_{A_2}^2 \approx M_A^2 \left( 1 + \frac{1}{4} \cot^2 \beta_s \sin^2 2\beta \right),
\] 
(7)

\[
m_{A_1}^2 \approx -\frac{3}{\sqrt{2}} \kappa v_s A_\kappa.
\] 
(8)

We are interested in the case that \( A_1 \) is very light. From Eq. [8] it can be seen that \( m_{A_1} \) can be very small if either \( \kappa \) or \( A_\kappa \) is very small, which is made possible by a Pecci-Quinn (PQ) symmetry: \( \kappa \to 0 \) and \( A_\kappa \to 0 \). We can achieve a small mixing angle by the cancellation between the two terms in the numerator of Eq. [6], by setting

\[
M_A^2 \sin 2\beta - 3\lambda \kappa v_s^2 = \sqrt{2} \lambda v_s \left( A_\lambda - \sqrt{2} \kappa v_s \right) \approx 0 \quad \Rightarrow A_\lambda \approx \sqrt{2} \kappa v_s.
\] 
(9)

Explicitly, here we give a sample point in the parameter space:

\[
\lambda = 1, \ v_s = 212 \text{ GeV}, \ \kappa = 10^{-3}, \ A_\lambda = 0.3 \text{ GeV}, \ A_\kappa = -1 \text{ GeV}, \ \tan \beta = 10,
\]

then it can give

\[
m_{A_1} = 0.67 \text{ GeV}, \ \mu = 150 \text{ GeV}, \ \tan \theta_A = 0.5 \times 10^{-4}.
\]

We have the following parameters in the NMSSM in addition to those of the MSSM: \( \lambda, \ \kappa, \ A_\lambda, \ A_\kappa, \) and \( v_s \) \( (m_S^2) \) has been eliminated by one of the tadpole equations in the electroweak
symmetry breaking.) Since $\lambda v_s/\sqrt{2} = \mu$, we can use $\mu$ and $\lambda$ in place of $v_s$. Also from Eqs. \((4), (8)\) and \((6)\) we can trade $\kappa$, $A_\lambda$, and $A_\kappa$ for $m_{A_1}^2$, $m_{A_1}$, and $\sin \theta_A$. The small $m_{A_1}$ can be achieved by requiring $\kappa \to 0$ in Eq. \((8)\) while keeping $v_s$ and $A_\kappa$ typical. The small mixing angle, on the other hand, is achieved by the condition in Eq. \((9)\) such that the fine-tuned cancellation is possible to give a small value of $\tan \theta_A$. We admit that this is a fine tuning requirement. Recall in the CP violating supersymmetry a natural mechanism to suppress the contributions from various sources of CP violating phases is to have a cancellation among various sources [12]. If the measurement of EDM continues to push to more stringent limits, more and more fine-tuned cancellations are needed to suppress the SUSY contributions.

FIG. 1: Decay branching ratios for the light pseudoscalar Higgs boson versus the mixing angle $\sin \theta_A$ for $\lambda = 1, \mu = 150, M_2 = 500$ GeV. (a) $m_{A_1} = 0.1$ GeV and (b) $m_{A_1} = 5$ GeV.
III. DECAY.

A lot of existing constraints on the lightest pseudoscalar Higgs boson $A_1$ depend on the mixing angle $\sin \theta_A$. When $\sin \theta_A$ goes to zero, the $A_1$ decouples and behaves like the singlet. This light $A_1$ can be extremely light without violating any existing data. It was pointed out that it can be produced in the scalar Higgs boson decay, $H_1 \to A_1A_1$, which is due to the term $\lambda \tilde{S} \tilde{H}_u \tilde{H}_d$ in the superpotential. We found in this work that there is another novel signature for this light $A_1$ from the same term. We calculate the associated production of $A_1$ with a pair of charginos, followed by $A_1 \to \gamma \gamma$ decay at hadronic and $e^+e^-$ colliders. This is an undebatable signal of the decoupling regime of the NMSSM.

In the limit of zero mixing, the $A_1$ only couples to a pair of charginos and neutralinos. Therefore, the dominant decay mode is $\gamma \gamma$ via a chargino loop if $m_{A_1}$ is very light. When we turn on the small mixing angle, other modes, such as $q\bar{q}$, $\ell^+\ell^-$, and $gg$, appear, which will eventually dominate when the mixing angle is larger than $O(10^{-3})$. We show a typical decay branching ratio versus the mixing angle for $m_{A_1} = 0.1, 0.5$ GeV in Fig. 1. When $m_{A_1}$ is as light as 0.1 GeV, only the $e^+e^−$ and $\gamma \gamma$ modes are possible. The $e^+e^−$ mode scales as $\sin^2 \theta_A$, and so the $e^+e^−$ mode increases sharply as $\sin \theta_A$ increases in Fig. 1(a). As $m_{A_1}$ increases other $f\bar{f}$ modes open up, such as $\tau^+\tau^−, c\bar{c}, gg$. As long as $\sin \theta_A \lesssim 10^{-3}$ the $\gamma \gamma$ dominates the decay of $A_1$.

IV. ASSOCIATED PRODUCTION.

The coupling of $A_i$ to charginos comes from the usual Higgs-Higgsino-gaugino source and, specific to NMSSM, from the term $\lambda \tilde{S} \tilde{H}_u \tilde{H}_d$ in the superpotential. The interaction is given by

$$L_{A\chi^+\chi^+} = i\bar{\chi}_i^+ \left( C_{ij} P_L - C_{ji}^* P_R \right) \tilde{\chi}_j^+ A_2$$

$$+ i\bar{\chi}_i^+ \left( D_{ij} P_L - D_{ji}^* P_R \right) \tilde{\chi}_j^+ A_1 ,$$

(10)
FIG. 2: Production cross sections for $e^- e^+ \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- A_1$ at the ILC with $\sqrt{s} = 0.5$, 1, 1.5 TeV. We have chosen $\lambda = 1$, $\sin \theta_A = 10^{-4}$, $\mu = 150$ GeV, $M_2 = 500$ GeV, and $\tan \beta = 10$.

where

$$C_{ij} = \frac{g}{\sqrt{2}} \left( \cos \beta \cos \theta_A U_{i1}^* V_{j2}^* + \sin \beta \cos \theta_A V_{j1}^* U_{i2}^* \right)$$

$$- \frac{\lambda}{\sqrt{2}} \sin \theta_A U_{i2}^* V_{j2}^* ,$$

$$D_{ij} = \frac{g}{\sqrt{2}} \left( - \cos \beta \sin \theta_A U_{i1}^* V_{j2}^* - \sin \beta \sin \theta_A V_{j1}^* U_{i2}^* \right)$$

$$- \frac{\lambda}{\sqrt{2}} \cos \theta_A U_{i2}^* V_{j2}^* ,$$

(11)

where $P_{L,R} = (1 \mp \gamma_5)/2$ are the chiral projectors.

We stress in passing that in the limit of zero mixing, the production of $A_1$ through the Drell-Yan process $e^+ e^- / pp \rightarrow A_1 \Phi$ is very suppressed. So is the gluon fusion since only quarks can mediate inside the loops. The associated production of $A_1$ with a chargino pair proceeds via the Feynman diagrams, in which the $A_1$ radiates off the chargino legs. The radiation off the intermediate $Z$ is not considered in the very small mixing limit. Note that the production is proportional to $|\lambda \cos \theta_A U_{i2} V_{j2}|^2$, which implies a large Higgsino component in $\tilde{\chi}_1^+$ is necessary for large cross sections. Details of the calculation will be given in a future publication. We choose $\mu = 150$ GeV and a much larger $M_2 = 500$ GeV, $\lambda = 1$ and $\sin \theta_A = 10^{-4}$ in our results. We show the production cross sections at $e^+ e^-$ colliders versus

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1 We have considered the largest possible value of $\lambda$, which should be of the order of $O(1)$. The size is limited by the perturbativity argument when the Yukawa coupling is evolved to the GUT scale. We have followed the prescription from other papers. In general, the perturbativity argument is rather loose.
FIG. 3: Production cross sections for $pp \to \tilde{\chi}_1^+ \tilde{\chi}_1^- A_1$ at the LHC. We have chosen $\lambda = 1$, $\sin \theta_A = 10^{-4}$, $\mu = 150$ GeV, $M_2 = 500$ GeV, and $\tan \beta = 10$.

$m_{A_1}$ for $\sqrt{s} = 0.5, 1, 1.5$ TeV in Fig. 2. Note that the cross section is insensitive to $\sin \theta_A$ as long as it is less than $10^{-2}$. Also, in this near-zero mixing region, the cross section scales as $\lambda^2$. With $O(500)$ fb$^{-1}$ yearly luminosity at the ILC, the number of raw events is of the order of $O(500)$. The signature is very spectacular with a pair of charged leptons and a pair of photons with a large missing energy. In contrast to the process of $h \to A_1 A_1 \to 4 \gamma$ [13], the photon pair is less collimated because the $A_1$ radiating off the chargino would not be as energetic as the $A_1$ from Higgs decay. Almost all SM backgrounds are reducible once the photon pair and the charged lepton pair are identified together with large missing energies.

The leptonic branching ratio of the chargino can increase if the slepton or sneutrino mass is relatively light. One can also increase the detection rates by including the hadronic decay of the charginos. Therefore, in the final state we can have (i) two charged leptons + two photons + $E_T$, (ii) one charged lepton + two jets + two photons + $E_T$, or (iii) 4 jets + two photons + $E_T$.

We show the production cross section for $pp \to \tilde{\chi}_1^+ \tilde{\chi}_1^- A_1$ at the LHC in Fig. 3 with the same set of parameters as in Fig. 2. We obtain a cross section slightly shy of $O(1)$ fb. With a yearly luminosity of 100 fb$^{-1}$ one can have about $O(100)$ raw events. It remains possible to detect the pseudoscalar Higgs boson and chargino decays. Experiments can search for

There may be some other new physics that appear well below the GUT scale. But roughly $\lambda \approx O(1)$ is the upper limit applied to $\lambda$ for the perturbativity reason.
the same final states that we listed for the ILC. Almost all SM backgrounds are reducible if the photon pair can be resolved and measured, together with the charged leptons or jets plus missing energies.

The critical issue here is whether the LHC experiment can resolve the two photons in the decay of the pseudoscalar Higgs boson. We perform a monte carlo study for the production of $\tilde{\chi}^+_1 \tilde{\chi}^-_1 A_1$ followed by the decay of $A_1 \rightarrow \gamma \gamma$. Since $A_1$ is a pseudoscalar, it is sufficient to study the $2 \rightarrow 2$ phase-space decay of $A_1$. We impose transverse momentum and rapidity requirements on the photons:

$$p_T > 10 \text{ GeV}, \quad |y_\gamma| < 2.6,$$  \hspace{1cm} (12)

which are in accord with the ECAL of the CMS detector \[16\]. The resolution of the “preshower” detector quoted in the report is as good as 6.9 mrad. We shall use 10 mrad as our minimum separation of the two photons that the detector can resolve. We show the distribution of the sine of the opening angle between the two photons for $M_{A_1} = 0.1, 1, 5$ GeV in Fig. 4. It is easy to understand that for $A_1$ as light as 0.1 GeV all the cross sections are within the opening angle $\theta_{\gamma\gamma} < 0.01$ rad. When $M_{A_1}$ increases to 1 GeV, more than half of the cross sections are beyond 0.01 rad. For $M_{A_1}$ as large as 5 GeV almost all cross sections are beyond $\theta_{\gamma\gamma} > 0.01$ rad. We show the resultant cross sections for $M_{A_1} = 0.1 − 5$ GeV with $p_T > 10 \text{ GeV}, |y_\gamma| < 2.6$, and $\theta_{\gamma\gamma} > 0.01$ rad in Table I. Suppose the LHC can accumulate $O(500 − 1000) \text{ fb}^{-1}$ luminosity, so $M_{A_1}$ as low as $0.3 − 0.4$ GeV are possible to be detected. For a mere $O(100) \text{ fb}^{-1}$ luminosity, the size of the cross section in Table I shows that it is only possible to detect $m_{A_1} > 1$ GeV.

The final issue is the background suppression. We have shown in Fig. 4 that for $m_{A_1} \sim 0.1$ GeV, almost all cross section lies below $\theta_{\gamma\gamma} < 0.01$, which is our conservative choice of resolution according to the preshower detector of the CMS. However, when $m_{A_1} \gtrsim 1$ GeV, more than half of the cross section survives this $\theta_{\gamma\gamma} > 0.01$ cut. We can also reconstruct the invariant mass of the photon pair to identify the pseudoscalar Higgs boson $A_1$ and separate it from the other SM mesons such as $\pi^0$ and $\eta$. Photon and lepton isolation cuts are the most useful ones to reject the jet-faking background and other QCD background. The remaining backgrounds are mostly gauge-boson pair and $t\bar{t}$ plus photons/jets production with the photons/jets radiating off fermion or gauge boson legs. Although they are irreducible, they are of higher order in couplings and should be small. Perhaps, the more serious background
FIG. 4: The differential cross section versus the sine of the opening angle between the two photons for $\lambda = 1$ and $\sin \theta_A = 10^{-4}$ at the LHC. Requirements of $p_T > 10$ GeV and $|y_\gamma| < 2.6$ are imposed.

issue in the LHC environment may be the combinatorial background because of many photons within a jet. Again, using strong photon-pair isolation (that is without hadronic jets around the photon pair) one should be able to substantially reduce this background.

V. DISCUSSIONS AND CONCLUSIONS.

One may ask if a very light pseudoscalar Higgs boson is consistent with the muon anomalous magnetic moment ($g - 2$) because it can contribute substantially to $g - 2$ at both 1-loop and 2-loop levels. However, it was shown that the 2-loop Barr-Zee type contributions with a light pseudoscalar can be of comparable size as the 1-loop contributions and opposite in sign [17]. Note that the contributions of the light $A_1$ of the NMSSM go to zero as $\sin \theta_A \to 0$. In the NMSSM, there could also be a light neutralino [11] that can contribute to $g - 2$. In addition, there are many parameters in the MSSM, such as gaugino and sfermion masses, which the $g - 2$ depends on. Thus, one can carefully take into account both 1- and 2-loop contributions and by adjusting the NMSSM parameters, such that the $g - 2$ constraint is
satisfied. There are other constraints on a light pseudoscalar from rare $K$ and $B$ meson decays, such as $b \to sA_1$ and $s \to dA_1$, $B - \overline{B}$ mixing, $B_s \to \mu^+\mu^-$, and $\Upsilon \to A_1\gamma$ [11, 18]. However, it is obvious that in these processes the light pseudoscalar interacts via the mixing with the MSSM pseudoscalar. Thus, in the limit of zero-mixing the constraints on the light $A_1$ can be easily evaded.

The major difference between MSSM and NMSSM is the existence of a singlet field, which gives rise to a scalar, a pseudoscalar, and a neutralino, in addition to the particle contents of the MSSM. We have shown that it is possible to have a very light pseudoscalar with a tiny mixing with the MSSM pseudoscalar. Such a light pseudoscalar boson is consistent with all existing constraints. The discovery mode has been shown [2] to be $H \to A_1A_1$, which enjoys a large production cross section. However, the photon pair from the $A_1$ decay may be too collimated. In this paper, we have pointed out another unambiguous signature from the associated production of the light pseudoscalar with a pair of charginos at the LHC and ILC, with a pair of charged leptons and a pair of photons plus large missing energy in the final state. We have also shown that the event rates at the LHC and ILC should be enough to identify such a signature when $M_{A_1}$ is larger than 1 GeV.

| $M_{A_1}$ (GeV) | Cross Section (fb) |
|-----------------|--------------------|
| 0.1             | 0.0                |
| 0.2             | 0.011              |
| 0.3             | 0.0405             |
| 0.4             | 0.078              |
| 0.5             | 0.12               |
| 1               | 0.26               |
| 2               | 0.38               |
| 3               | 0.42               |
| 4               | 0.44               |
| 5               | 0.44               |

TABLE I: Cross sections in fb for associated production of $\tilde{\chi}^+_1 \tilde{\chi}_1^- A_1$ followed by $A_1 \to \gamma\gamma$. The cuts applied to the two photons are: $p_T > 10$ GeV, $|y_{\gamma}| < 2.6$, and $\theta_{\gamma\gamma} > 10$ mrad.
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