A SIGNATURE OF ISOLATED HARD PHOTONS FROM PHOTINO DECAY AT THE SSC

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Summary

We have pursued the possible signatures of isolated hard photons produced in hadron collisions at energy of the SSC. Special attention is paid to a possible photon source in an alternative SUSY phenomenology. We find that the signature of photons from the photino decay can be observed over the possible backgrounds at the energy of SSC with integrated luminosity above 10^{38} cm^{-2}.

Introduction

We study the possible signatures of isolated hard photons produced in hadron collisions, in particular, at energy of the Superconducting Super Collider (SSC). Various reactions for producing hard photons in the framework of the standard model through QCD mechanism have been widely studied and the most of consequences are now predictable at higher energies.

On the other hand, it has recently been argued that there might be a new photon source in a variety of the supersymmetry (SUSY) models. The possibility is argued in connection with the question of the least supersymmetric particle(LSP). In the conventional SUSY phenomenology the photino, $\tilde{\gamma}$, is regarded as the LSP and hence to be responsible for carrying missing energy. In an alternative case, the LSP is a higgsino $\tilde{H}$ (or a mixture of photino, zino and higgsinos). Then $\tilde{\gamma}$ would decay into $\gamma\tilde{H}$ thereby the distinctive signature of prompt photon appears in association with missing E_T carried by $\tilde{H}$. The SUSY signature is usually the presence of missing E_T. But in this case a hard photon is uniquely accompanying.

It is discussed that the mode $\tilde{\gamma} \to \gamma\tilde{H}$ is possibly the dominant one and the decay is prompt unless the photino mass is sufficiently light.[1,2]

The above possibility emerges from the point of view of a supersymmetry theory coupled to N=1 supergravity, and cosmological considerations[3]. The mass of photino is suggested to be likely $O(10)$ GeV. This may be consistent to the so called GUT relation, the photino mass ≈ 1/6 gluino mass, if the gluino mass is larger than 45 GeV as suggested by the recent analysis[4] of the CERN-SPS collider data.

Here we notice that in the case of the sneutrino $\tilde{\nu}$ being the LSP, the decay $\tilde{\gamma} \to \nu\tilde{\nu}$ can occur. Phenomenologically this would give a similar missing E_T signature as in the conventional SUSY case. Also we mention that the R-parity violating SUSY[5] gives rise to $\tilde{\gamma} \to \gamma\nu$, giving a similar E_T signature to $\gamma\tilde{H}$ in the case of an alternative SUSY. In any case, the signature of isolated hard photon associated with missing E_T is an interesting one and is the main subject in the present study. We have previously studied the subject for both cases of the Tevatron collider and SSC.[6] The present report concerns only the case of SSC where the associated production of photino and gluino with higher masses is more feasible.

Calculation of SUSY Signal and Backgrounds

There is a number of processes for producing photons in the final states. For any interesting process, other competing processes play as backgrounds while each process has its own right to be explored at higher energies.

For the collider physics from 1 TeV to 50 TeV a set of comprehensive calculations for different physics models through various subprocesses is available[7,8]. For our purpose of the phenomenological study we use the Monte Carlo program ISAJET[9] which offers realistic outputs for the standard model and supersymmetry model.

The detector used in the calculation consisted of a calorimeter with uniform cells accepting $\Delta\eta$ =0.1 and $\Delta\phi$=5°, where η and ϕ are pseudo-rapidity and azimuthal angle variables. The energy of each particle is confined to a single cell (i.e. no shower spread is taken into account) with the energy resolutions such as

$$\Delta E/E \text{ (electromagnetic)} = 15\%/\sqrt{E}$$

$$\Delta E/E \text{ (hadronic)} = 35\%/\sqrt{E}$$

The cell threshold is set to be 2 GeV. For the photon detection we assume that there is no mismeasuring of electrons in the electromagnetic calorimeter with 100% of efficiency of electron tracking.

Susy Signal

The reaction to be observed is

$$pp \to \gamma + E_T(\text{miss}) + X(\text{jets}) \qquad (1)$$

The primary subprocess is $gg \to \tilde{g}\tilde{\gamma}$ (assuming $m_{\tilde{q}} > m_{\tilde{g}}$) with principal subsequent decays $\tilde{g} \to q\bar{q}\tilde{\gamma} \to q\bar{q}\gamma\tilde{H}$ and $\tilde{\gamma} \to \gamma\tilde{H}$. Thus a hard photon arises, some of the times, from the photino decay and E_T(miss) is carried by $\tilde{H}$.

In the calculation, we take the branching ratio of $\tilde{\gamma} \to \gamma\tilde{H}$ to be 100 % and the decay angular distribution being isotropic. We adopt a certain mass range for SUSY particles, which is set from the considerations of relating cross sections and collider luminosity. The mass range of gluino is set to be between 100 GeV and 900 GeV for the SSC. This is the effective mass range estimated for the integrated luminosity of 10^{38} cm^{-2}, for exampl, by Eichten[8]. While, the mass range of photino is set somewhat arbitrary to be 10 to 30 GeV and that of higgsino to be 1 to 5 GeV. The mass of squark is always taken to be gluino mass plus 5 GeV conventionally.

The E_T distributions of photons and missing E_T distributions in this process are shown in Figs. 1 and 2 for two sets of masses.

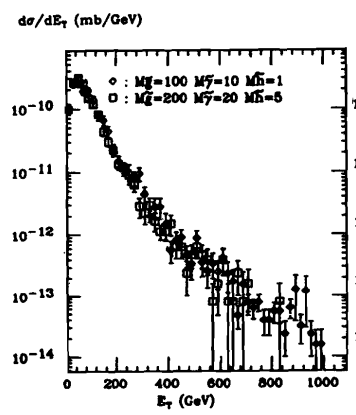

Fig.1 The E_T distribution of γs for the alternative SUSY at $\sqrt{s}$=40TeV and $|\eta|$<5.

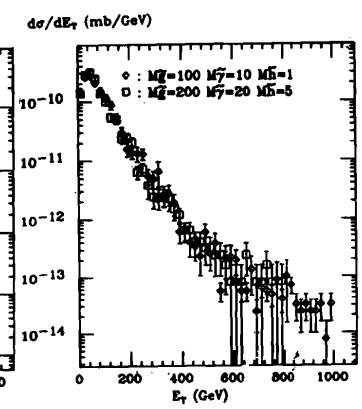

Fig.2 The missing E_T distribution for the alternative SUSY at $\sqrt{s}$=40TeV and $|\eta|$<5.

Backgrounds

We examine the following reactions as the possible principal background sources.

A) $\pi^0(\eta)$ productions

$$PP \to \pi^0(\eta) + X(\text{jets}) \qquad (2)$$

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The reaction is not really the process for producing photons at the subprocess, but gives a faked signature of photons at the observation, depending upon the energy of π^0 and the resolving power of the detector for two photon separation. For the usual collider detector, the unresolved decayed photons from π^0 with energy , say above 50 GeV, appear to be a fake photon. The same can be said to η production which amounts to a comparable yield of π^0 production at high E_T.[10] In this case those particles are considered to be the leading jet fragments. When the missing E_T is required to be associated with high E_T π^0, there might be distinctively different missing E_T sources. That is, one is light quarks (and gluons) jets and the other is heavy quarks jets. (See Fig. 4 below.) Hereafter we call the b and t quarks as heavy quarks with the t quark mass being 40 GeV.

B) Direct photon productions

A definite photon source at the subprocess is the direct photon production,

$$p\,p \to \gamma + X(\text{jets}) \qquad (3)$$

with the almost the same yield as π^0 at high energies, as shown in a previous study[11]. The direct photons are expected to be more isolated than π^0's and η's .

The direct double photon production is also anticipated via gg -> $\gamma\gamma$, $q\bar{q}$ -> $\gamma\gamma$, while the rate is expected to be about two order of magnitude lower than that of single photon production[12].

Figures 3 and 4 show the combined photon E_T distributions and the missing E_T distributions from the reactions (2) and (3), plotting separartely the contributions of light quarks jets and heavy quarks jets.

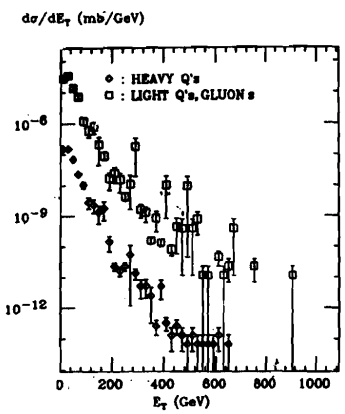

Fig.3 The E_T distribution of γs (any of γ, π^0 and η) for reactions (2) and (3) at $\sqrt{s}$=40TeV and $|\eta|$<5.

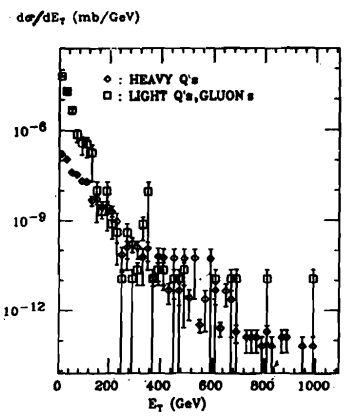

Fig.4 The missing E_T distributions for reactions (2) and (3) at $\sqrt{s}$=40TeV and $|\eta|$<5.

C) W and Z productions

Since W and Z decays are considered to be the principal standard model sources of missing E_T, the associated production with photons such as the following should be examined.

$$p\,p \to W + \gamma, \text{ with } W \to l\nu \qquad (4)$$

$$p\,p \to Z + \gamma, \text{ with } Z \to \nu\nu \qquad (5)$$

The production cross sections are given in refs. 7,8 for the case of SSC. In process (4), W can be measured with identifying the decayed lepton when the lepton identification efficiency is 100%. The $Z\gamma$ final state is expected to be more crucial as the background, in which $Z \to \nu\nu$ is missing. The calculation of the process (5) is not contained in the ISAJET. Fortunately the calculation for this process made by Baer is available.[13] The E_T distribution of associated photons is shown in Fig. 5.

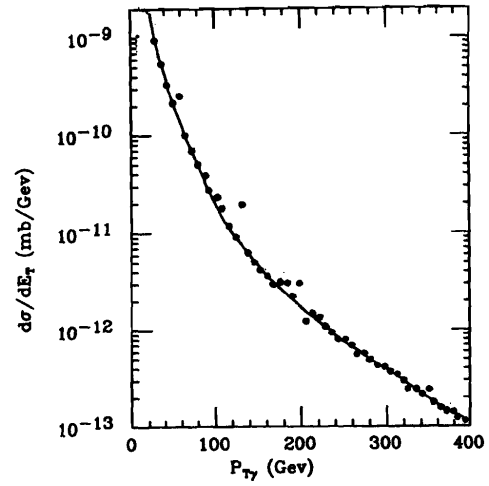

Fig.5 The E_T distributions of γs for pp→Zγ at $\sqrt{s}$=40TeV.

Results and Discussions

We show in Figs. 6 and 7 the photon E_T distributions and missing E_T distributions of the SUSY signals and the standard model backgrounds (including any of photons, π^0's, and η's). As seen in the figures the backgrouns dominate over the SUSY signals.

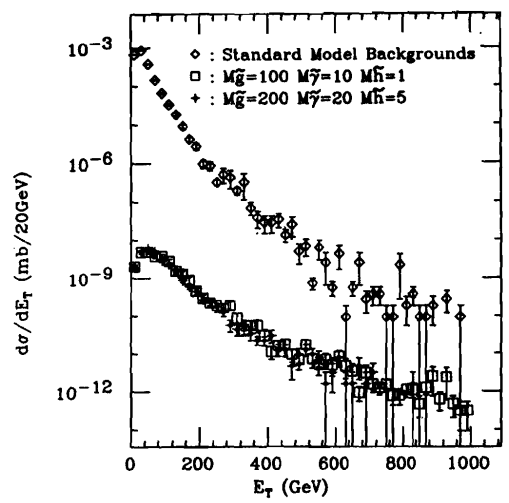

Fig.6 The E_T distributions of γs (any of γ, π^0 and η) for pp→γ+E_T(miss)+X(jets), for the standard model backgrounds and alternative SUSY. The jet E_T cut is 100GeV.

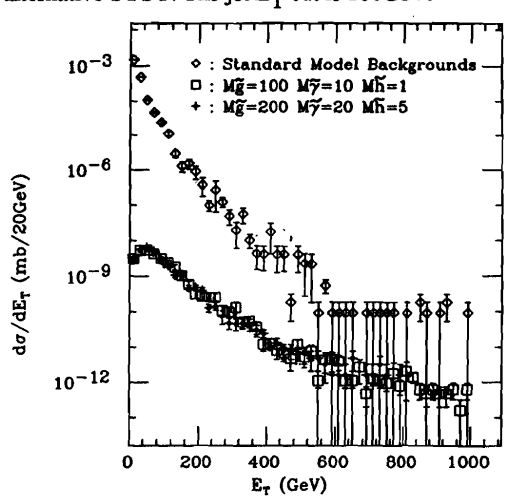

Fig.7 The missing E_T distribution for $pp \to \gamma + E_T(miss) + X(jets)$ for the standard model backgrounds and alternative SUSY. The jet E_T cut is 100GeV.

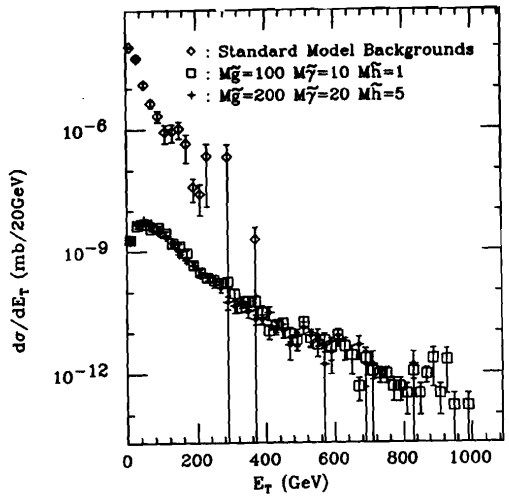

Fig.8 Same for Fig.6, except for making the total E_T sum cut to be less than 2500GeV and the E_T sum cut around the leading photons within R<0.2 to be less than 20GeV.

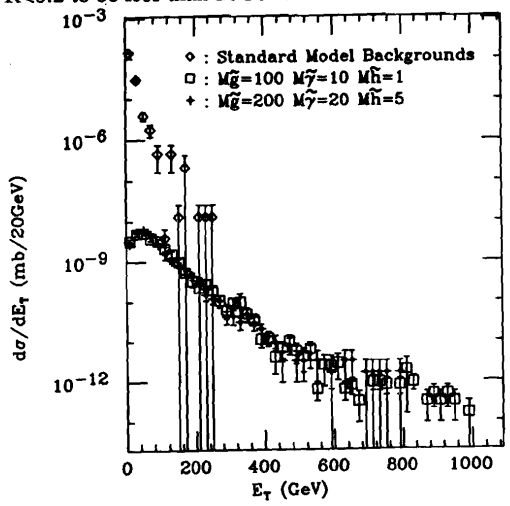

Fig.9 Same for Fig.7 , except for making cuts as in Fig.8.

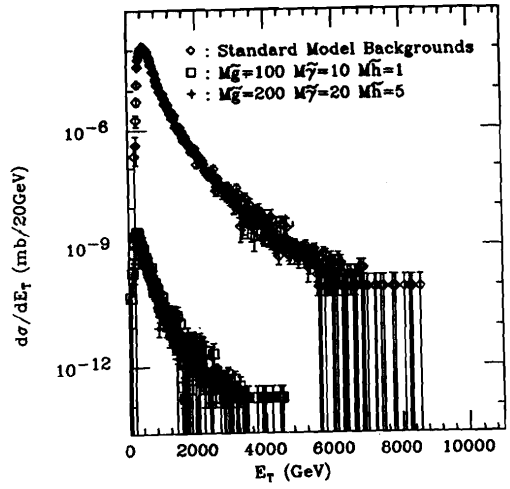

Fig.10 The total E_T distributions for $pp \to \gamma + E_T(miss) + X(jets)$, for the standard model and alternative SUSY.

The contributions of $W\gamma$ and $Z\gamma$ productions to the final state of the photon and missing E_T are small. Even for the $Z\gamma$, the photon E_T spectrum is lower and softer than that of the SUSY signals. (See Figs. 1 and 5.) Also these processes have pronounced forward and backward peaks of photons , and that is a useful characteristic in rejecting these processes as backgrounds.[6,13]

In order to find out the SUSY signals over the dominant backgrounds we first looked at the isolation of the photons in the following ways. We looked at the distribution of angle differences between the leading photon and missing E_T. The distributions for both of the SUSY signals and backgrounds are almost isotropic. We also checked the jet activity around the leading photon within the region R<1.0, where $R=\sqrt{(\Delta h)^2+(\Delta f)^2}$. No clear difference was seen between the SUSY signals and the background events. In other words, the jet activity around the photon of SUSY signals is not particularly quiet. Those examinations seem not to be so useful.

As a next step, we apply an energy cut to the total E_T and local E_T sum around the leading photons within the narrower R region. The photon E_T distribution and missing E_T distribution, with the total E_T cut to be less than 2500 GeV and the E_T sum cut for particles around the leading photon within R<0.2 to be less than 20 GeV are shown in Figs.8 and 9. The SUSY signals begin to overcome the backgrounds at above 400 GeV photon E_T and above 300 GeV missing E_T at the level of $10^{-38}cm^2$. For reference we show in Fig. 10 the total E_T distributions for both the signals and backgrounds.

It can be thus concluded that searching for a possible signature from an alternative SUSY at the SSC is promissing. It is perhaps to be emphasized that the current superstring inspired phenomenology suggests that a higgisino is likely to be the LSP.[14] We should also mention that searching for the photino decay will also be made with future high energy $e^+ e^-$ colliders.

Conclusion

We have performed a simulation study of the signatures of isolated hard photons associated with missing energy. It is found that searching for the photon signals from the photino decays at the SSC is promising. The signals can be confirmed with the integrated luminosity above $10^{38}cm^{-2}$ if an alternative SUSY with the higgisino being the LSP is the case.

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