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Production of SUSY Particles in Polarized γp Collisions

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Abstract

We discuss the production of several SUSY particles in the high energy collisions of the real photons off the protons within the MSSM. The polarizations of the colliding beams are also considered. The discovery mass limits for the squark and gluinos are presented and we conclude that the capacity of the future TeV scale γp colliders is quite promising in the search for SUSY particles.

1. Introduction

In recent years in addition to the well known TeV scale colliders such as $pp\,(p\bar{p})$, ep and e^+e^- machines the possibilities of the realization of γe, $\gamma\gamma$ and γp colliders have been proposed and discussed in detail [1]. Here one of the main motivation is to reach the TeV scale at a subprocess level. The collisions of protons from a large hadron machine with electrons from a linac is the most efficient way of achieving TeV scale at a constituent level in ep collisions [2]. A further interesting feature is the possibility of constructing γp colliders on the base of linac-ring ep-machines. This can be realized by using the beam of high energy photons produced by the Compton backscattering of laser photons off a beam of linac electrons. Actually this method was originally proposed to construct γe and $\gamma\gamma$ colliders on the bases of e^+e^- linacs [Ginzburg et.al ref.1]. For the physics program at γe and $\gamma\gamma$ machines see [3, 4]. Recently different physics phenomena which can be investigated at γp colliders have been considered in a number of papers [5, 6, 7]. It seems that these machines may open new possibilities for the investigations of the Standard Model and beyond it. For a review see [8].

On the other hand among the various extensions beyond the SM the supersymmetry idea seems to be a well-motivated strong candidate to investigate the new physics around TeV scale [9]. In SUSY inspired models the usual particle spectrum is doubled at least; every particle has a superpartner differing in spin by a half unit. Also two Higss doublets are needed to give mass to both up and down quarks and make the theory anomaly free. It is highly believed that superpartners of the known particles should have masses below 1 TeV in order not to loose the good features of the SUSY. The direct experimental evidence for the sparticles is still lacking and the results of the experiments in the existing colliders indicate that squarks have masses $m_{\tilde{q}} \geq 100GeV$; consequently higher energy scale should be probed and it is desirable to reach the TeV scale at a constituent level [10, 11]. Therefore it might be sensible to say that HERA, LEP, FERMILAB and LHC should be sufficient to check the idea of low energy SUSY, namely the scale between 100 GeV and 1 TeV, however experiments at all possible types of colliding beams would be inevitable to explore the new physics at the TeV scale.

In this work, we study the pair production of the squarks and gluino-squark production at TeV scale γp colliders. Several SUSY production processes such as $\gamma p \to \tilde{q}\tilde{w}X$, $\gamma p \to \tilde{w}\tilde{w}X$, $\gamma p \to \tilde{q}\tilde{g}X$, $\gamma p \to \tilde{q}\tilde{\gamma}X$ (or $\tilde{q}\tilde{z}$) and $\gamma p \to \tilde{q}\tilde{\bar{q}}X$ have already been discussed [6]. Also scalar leptoquark productions at TeV energy γp colliders have been investigated [7].

2. Susy Particle Productions

2.1. Pair Production of Squarks

The invariant amplitude for the subprocess $\gamma g \to \tilde{q}\tilde{\bar{q}}$ proceeds via the t-, u-channel squark exchange and four-point vertex interactions. For arbitrary polarization states of the initial beams $\mid M \mid^2$ is obtained as follows;

$$\mid M \mid^2 = (ee_{\tilde{q}}g_s)^2 \rho^{\mu\mu'}_{(\gamma)} Q_{\mu\nu} \rho^{\nu\nu'}_{(g)} Q^*_{\mu'\nu'} \tag{1}$$

where $\rho^{\mu\mu'}_{(\gamma)}$ and $\rho^{\nu\nu'}_{(g)}$ are the density matrices of the photon and gluon. $Q_{\mu\nu}$ is a tensor of rank two which includes 4-momenta of the interacting particles. For polarized and unpolarized cases the density matrices of photon and gluon are given as follows:

$$\begin{aligned} \rho^{(\gamma)}_{\mu\mu'} &= -\frac{1}{2} g_{\mu\mu'} \\ \rho^{(g)}_{\nu\nu'} &= -\frac{1}{2} g_{\nu\nu'} \qquad\qquad \textit{unpolarized case} \end{aligned} \tag{2}$$

$$\begin{aligned} \rho^{(\gamma)}_{\mu\mu'} &= \frac{1}{2}(1 + \overrightarrow{\xi} \cdot \overrightarrow{\sigma})_{ab} e^{(a)}_{\mu} e^{(b)}_{\mu'} \\ \rho^{(g)}_{\nu\nu'} &= \frac{1}{2}(1 + \overrightarrow{\eta} \cdot \overrightarrow{\sigma})_{cd} e^{(c)}_{\nu} e^{(d)}_{\nu'} \qquad \textit{polarized case} \end{aligned} \tag{3}$$

where $\overrightarrow{\sigma} = (\sigma_1, \sigma_2, \sigma_3)$ are the usual Pauli matrices, $\overrightarrow{\xi} = (\xi_1, \xi_2, \xi_3)$ and $\overrightarrow{\eta} = (\eta_1, \eta_2, \eta_3)$ are Stokes parameters of the photon and gluon respectively. In our calculations we take into consideration only circular polarizations that is defined by second component of the above parameters. For the right (left) circular polarization, ξ_2, η_2 take the value of $+1(-1)$. $e_\mu^{(a)}$ $(a = 1, 2)$ are the polarization unit 4-vectors which are orthogonal to each other and to the momenta of the colliding particles.

The polarized differential cross-section of this subprocess can be calculated in terms of the usual Mandelstam variables $\hat{s} = (k_1 + k_2)^2, \hat{t} = (k_1 - p_1)^2$ and $\hat{u} = (k_1 - p_2)^2$ as :

$$\frac{d\hat{\sigma}}{d\hat{t}} = \left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{np} + \xi_2\eta_2 \left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{pol} \tag{4}$$

$$\begin{aligned}\left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{np} = \frac{e^2 e_{\tilde{q}}^2 g_s^2}{8\pi \hat{s}^2} \Bigg[& 1 + \frac{m_{\tilde{q}}^2(3m_{\tilde{q}}^2 - \hat{s} - \hat{t})}{2(\hat{s} + \hat{t} - m_{\tilde{q}}^2)^2} + \frac{(3m_{\tilde{q}}^2 - \hat{s} + \hat{t})}{4(m_{\tilde{q}}^2 - \hat{t})} \\ & + \frac{m_{\tilde{q}}^2(m_{\tilde{q}}^2 + \hat{t})}{(m_{\tilde{q}}^2 - \hat{t})^2} + \frac{(5m_{\tilde{q}}^2 + 2\hat{s} - \hat{t})}{4(\hat{s} + \hat{t} - m_{\tilde{q}}^2)} + \frac{(\hat{s} - 2m_{\tilde{q}}^2)(\hat{s} - 4m_{\tilde{q}}^2)}{4(m_{\tilde{q}}^2 - \hat{t})(\hat{s} + \hat{t} - m_{\tilde{q}}^2)} \Bigg]\end{aligned} \tag{5}$$

$$\left(\frac{d\hat{\sigma}}{d\hat{t}}\right)_{pol} = \frac{e^2 e_{\tilde{q}}^2 g_s^2}{16\pi \hat{s}^2} \left[\frac{m_{\tilde{q}}^2(\hat{s} - 2\hat{t}) + m_{\tilde{q}}^4 + \hat{s}\hat{t} + \hat{t}^2}{(m_{\tilde{q}}^2 - \hat{s} - \hat{t})(m_{\tilde{q}}^2 - \hat{t})} \right] \tag{6}$$

After performing the integration over $\hat{t}$ one can easily obtain the total cross section for the subprocess $\gamma g \to \tilde{q}\bar{\tilde{q}}$ as follows :

$$\hat{\sigma}(\hat{s}, m_{\tilde{q}}, \xi_2, \eta_2) = \hat{\sigma}_{np} + \xi_2\eta_2\hat{\sigma}_{pol} \tag{7}$$

$$\hat{\sigma}_{np} = \frac{\pi\alpha e_{\tilde{q}}^2 \alpha_s}{2\hat{s}} \left[2\beta(2 - \beta^2) - (1 - \beta^4) ln \frac{1 + \beta}{1 - \beta} \right] \tag{8}$$

$$\hat{\sigma}_{pol} = \frac{\pi\alpha e_{\tilde{q}}^2 \alpha_s}{2\hat{s}} \left[2\beta - 2(1 - \beta^2) ln \frac{1 + \beta}{1 - \beta} \right] \tag{9}$$

here α $(e = \sqrt{4\pi\alpha})$ is the fine structure constant, $e_{\tilde{q}}$ is the squark charge, α_s $(g_s = \sqrt{4\pi\alpha_s})$ is the strong coupling constant and $\beta = (1 - 4m_{\tilde{q}}^2/\hat{s})^{1/2}$. The above expression in (7) is a cross section for left-squarks or right-squarks only, and a color factor of $C = 1/2$ is already included. In order to obtain the total cross section for the process $\gamma p \to \tilde{q}\bar{\tilde{q}}X$ one should integrate $\hat{\sigma}$ over the gluon and photon distributions. Before this integration we should make the following change of variables: first expressing $\hat{s}$ as $\hat{s} = x_1 x_2 s$ where $\hat{s} = s_{\gamma g}$, $s = s_{ep}$, $x_1 = E_\gamma/E_e$, $x_2 = E_g/E_p$ and furthermore calling $\tau = x_1 x_2$, $x_2 = x$ then one obtains $dx_1 dx_2 = dx d\tau/x$. The limiting values are $x_{1,max} = 0.83$ in order to get rid of the background effects in the Compton backscattering, particularly e^+e^- pair production in the collision of the laser with the high energy photon in the conversion region, $x_{1,min} = 0$, $x_{2,max} = 1$, $x_{2,min} = \frac{\tau}{0.83}$, $\hat{s}_{min} = 4m_{\tilde{q}}^2$. Then we can write the total cross section with right circular polarized laser and "spin-parallel" proton beam polarized longitudinally as follows:

$$\sigma_{R\uparrow} = \int_{4m_{\tilde{q}}^2/s}^{0.83} d\tau \int_{\tau/0.83}^{1} dx \frac{1}{x} \Big\{ P \Big[f_{+}^{\gamma}(\frac{\tau}{x}) f_{+/\uparrow}^{g}(x) \hat{\sigma}_{++} + f_{+}^{\gamma}(\frac{\tau}{x}) f_{-/\uparrow}^{g}(x) \hat{\sigma}_{+-} \Big]$$
$$+ (1-P) \Big[f_{+}^{\gamma}(\frac{\tau}{x}) f_{+/\downarrow}^{g}(x) \hat{\sigma}_{+-} + f_{+}^{\gamma}(\frac{\tau}{x}) f_{-/\downarrow}^{g}(x) \hat{\sigma}_{++} \Big] \Big\} \qquad (10)$$

where P is the polarization percentage of spin-parallel protons in the beam and for a maximum attainable degree of 70% longitudinal polarization $P = 0.85$. Also $f_{\pm}^{\gamma}$ and $f_{\pm}^{g}$ are the polarized distributions for the photon and gluon inside the proton, respectively.

Similarly one can easily obtain $\sigma_{R\downarrow}, \sigma_{L\uparrow}, \sigma_{L\downarrow}$ for the other polarization cases. In these equations the following short notation for the subprocess cross-sections with respect to the values of Stokes parameters is used:

$$\begin{aligned}
\hat{\sigma}(\tau s, m_{\tilde{q}}, \xi_2 = +1, \eta_2 = +1) &\equiv \hat{\sigma}_{++} \\
\hat{\sigma}(\tau s, m_{\tilde{q}}, \xi_2 = +1, \eta_2 = -1) &\equiv \hat{\sigma}_{+-} \\
\hat{\sigma}(\tau s, m_{\tilde{q}}, \xi_2 = -1, \eta_2 = +1) &\equiv \hat{\sigma}_{-+} \\
\hat{\sigma}(\tau s, m_{\tilde{q}}, \xi_2 = -1, \eta_2 = -1) &\equiv \hat{\sigma}_{--} \qquad (11)
\end{aligned}$$

Eq.(10) can be rearranged according to the unpolarized and difference distributions for gluon inside the proton and can be written in the form :

$$\sigma_{R\uparrow} = \int_{4m_{\tilde{q}}^2/s}^{0.83} d\tau \int_{\tau/0.83}^{1} dx \frac{1}{x} \Big\{ P \Big[f_{+}^{\gamma}(\frac{\tau}{x}) f_{unpol}^{g}(x) \hat{\sigma}_{np} + f_{+}^{\gamma}(\frac{\tau}{x}) (-\Delta f_{pol}^{g}(x)) \hat{\sigma}_{pol} \Big]$$
$$+(1-P) \Big[f_{+}^{\gamma}(\frac{\tau}{x}) f_{unpol}^{g}(x) \hat{\sigma}_{np} + f_{+}^{\gamma}(\frac{\tau}{x}) (+\Delta f_{pol}^{g}(x)) \hat{\sigma}_{pol} \Big] \Big\}. \qquad (12)$$

In the numerical calculations we used the unpolarized and difference distributions, f_{unpol}^{g} and Δf_{pol}^{g} taken from [14]:

$$f_{unpol}^{g}(x) = \frac{1}{x} \Big[(2.62 + 9.17x)(1-x)^{5.90} \Big] \qquad (13)$$

and

$$\Delta f_{pol}^{g} = 16.3001 x^{-0.3} (1-x)^{7} \qquad (14)$$

Also the energy spectrum of the high energy real photons $f_{\gamma}(y)$ is given as follows [Ginzburg et al. in ref.1]:

$$f_{\pm}^{\gamma}(y) = \frac{1}{\sigma}\frac{2\pi\alpha^2}{\zeta m_e^2}\Bigg[\quad 1 - y + \frac{1}{1-y} - \frac{4y}{\zeta(1-y)} + \frac{4y^2}{\zeta^2(1-y)^2} - \lambda_e\lambda_\gamma \frac{y(2-y)}{(1-y)}\left(\frac{2y}{\zeta(1-y)} - 1\right)\Bigg] \tag{15}$$

where $\zeta = 4E_e\omega_0/m_e^2$, $y = \frac{E_\gamma}{E_e}$. Here $\lambda_e, \lambda_\gamma$ are the linac electron and laser photon helicities respectively and σ is the total Compton cross section:

$$\sigma = \sigma^0 + \lambda_e\lambda_\gamma\sigma^1 \tag{16}$$

$$\sigma^0 = \frac{\pi\alpha^2}{\zeta m_e^2}\left[(2 - \frac{8}{\zeta} - \frac{16}{\zeta^2})ln(\zeta+1) + 1 + \frac{16}{\zeta} - \frac{1}{(\zeta+1)^2}\right] \tag{17}$$

$$\sigma^1 = \frac{\pi\alpha^2}{\zeta m_e^2}\left[(2 + \frac{4}{\zeta})ln(\zeta+1) - 5 + \frac{2}{(\zeta+1)} - \frac{1}{(\zeta+1)^2}\right] \tag{18}$$

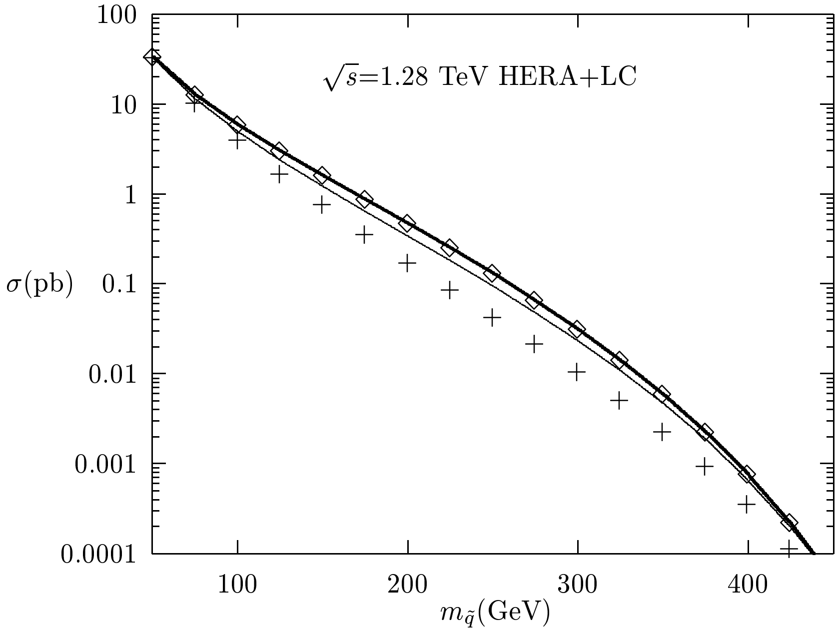
Here the optimum value of $y_{max} = 0.83$ corresponds to $\zeta = 4.83$ and $\lambda_e\lambda_\gamma = \pm 1$ correspond to the positive (or negative) laser helicity. To carry out the numerical integration we take $e_{\tilde{q}} = 2/3$ hence consider only u-type squarks and $\alpha_s = 0.1$ is taken. The results of the numerical calculations clearly indicate that the process $\gamma p \to \tilde{q}\tilde{\bar{q}}X$ has a detectable cross section. In Figs.1.(a-c), the dependence on the squark masses is shown for different γp colliders. The relevant parameters of these machines are given in Table 1.

Table 1. Parameters of γp colliders and discovery limits for scalar quarks with $e_{\tilde{q}} = 2/3$. (Note:$\sqrt{s_{\gamma p}}^{max} = 0.91\sqrt{s_{ep}}$)

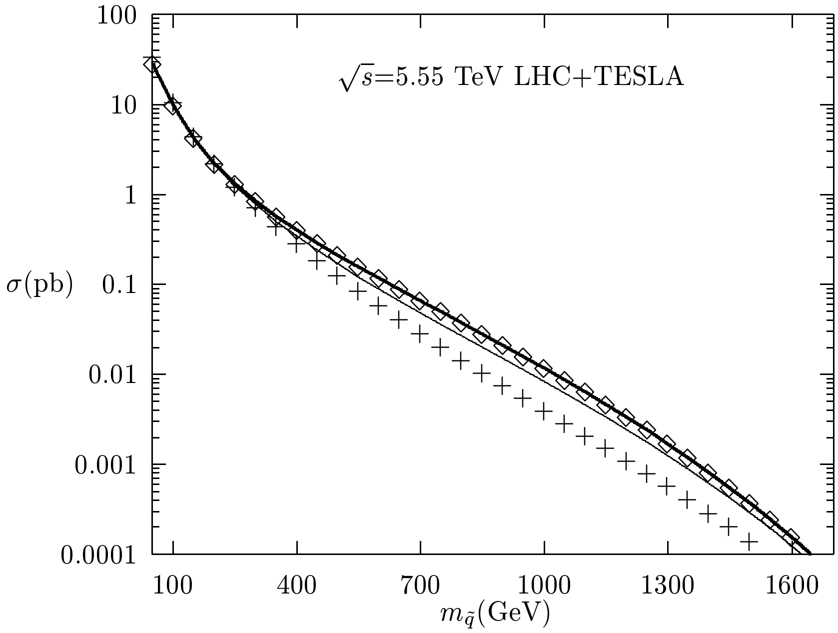
Machines	$\sqrt{s_{ep}}$ (TeV)	$\mathcal{L}_{\gamma p}$ $(10^{30}cm^{-2}s^{-1})$	$m_{\tilde{q}}$ (TeV) (non-degenerate) squarks	$m_{\tilde{q}}$ (TeV) (degenerate) squarks
HERA+LC	1.28	25	0.2	0.3
LHC+TESLA	5.55	500	0.85	1.1
LHC+e-Linac	3.04	500	0.6	0.7

Table 2. Discovery mass limits for scaler quarks and gluinos at different γp colliders

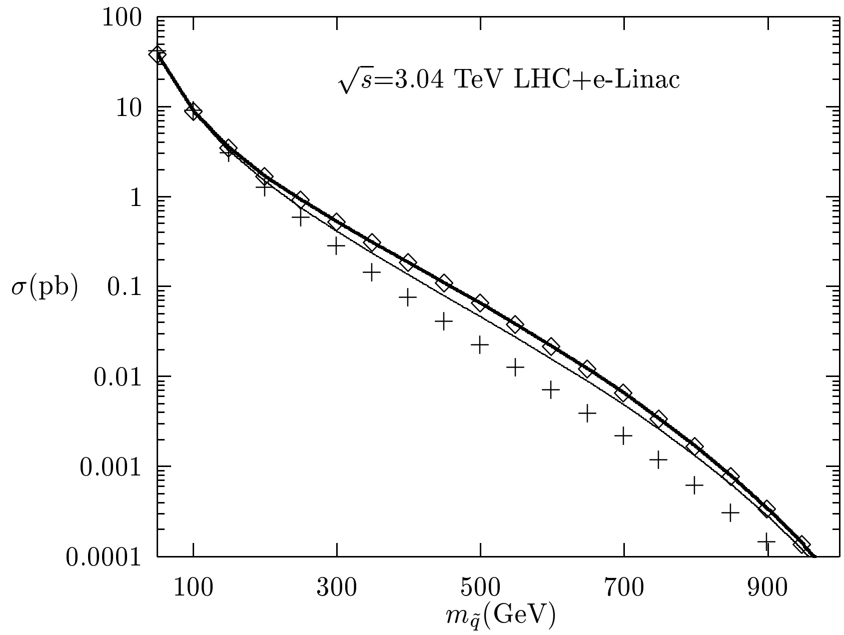
Machines	$\sqrt{s_{ep}}$ (TeV)	$m_{\tilde{u}} = m_{\tilde{g}}$ (TeV)	$m_{\tilde{u}} = 0.10$ $m_{\tilde{g}}$ (TeV)	$m_{\tilde{g}} = 0.10$ $m_{\tilde{u}}$ (TeV)
HERA+LC	1.28	0.17	0.32	0.21
LHC+TESLA	5.55	0.77	1.90	1.05
LHC+e-Linac	3.04	0.53	1.22	0.75


100
10
1
0.1
0.01
0.001
0.0001
σ(pb)
√s=1.28 TeV HERA+LC
100
200
300
400
m_q̃(GeV)

(a)


100
10
1
0.1
0.01
0.001
0.0001
σ(pb)
√s=5.55 TeV LHC+TESLA
100
400
700
1000
1300
1600
m_q̃(GeV)

(b)



(c)

Figure 1. (a-c) Production cross sections of squark pairs as a function of their masses for various γp colliders. In each figure the polarization states of the beams are indicated as follows: Line: Unpolarized beams, linespoints: right polarized laser, up protons, dots: right polarized laser, down protons.

On the other hand observation limit for the new particles is taken to be 100 events per running year (10^7 seconds). This level of observability is considered to be satisfactory since the background is expected to be clearer than that encountered in the hadron colliders where 1000 events/year is usually desired due to the strong background processes. Hence taking into account the luminosity values given in Table 1 [see Aydin et al. in ref.1], one can easily find from the Figs.1.(a-c) the upper mass limits for the squarks. These values of discovery limits are also tabulated in Table 1. For the d-type squarks $(\tilde{d}_{L,R}, \tilde{s}_{L,R}, \tilde{b}_{L,R})$ putting $e_{\tilde{q}} = -1/3$, results in the decrease of the cross section by a factor 1/4 , but the corresponding upper mass values are approximately some seventy percent of those in the last column of the Table 1. Furthermore the mixings among left and right squarks might be taken into consideration. Because their masses are expected to be close to each other, one can assume that $\tilde{q}_L$ and $\tilde{q}_R$ are degenerate in mass which points out that for the $\tilde{q}\bar{\tilde{q}}$ production one can always consider the sum of the two cross section for $\tilde{q}_L$ and $\tilde{q}_R$ production. Hence if we do this incoherent sum of $\tilde{q}_L$ and $\tilde{q}_R$ and with $m_{\tilde{q}_L} = m_{\tilde{q}_R}$ we must multiply the expression in (7) by an extra factor two, which increases the discovery limits for the squark masses. One additional assumption can be made by assuming five degenerate flavours of $\tilde{q}_L$ and $\tilde{q}_R$, (namely except stop) which multiplies the individual squark pair production cross section, Eq.(6) by about a factor of six and a half. We see that the cross sections for different initial beam polarizations do not differ much which reflects the scalar nature of the squarks.

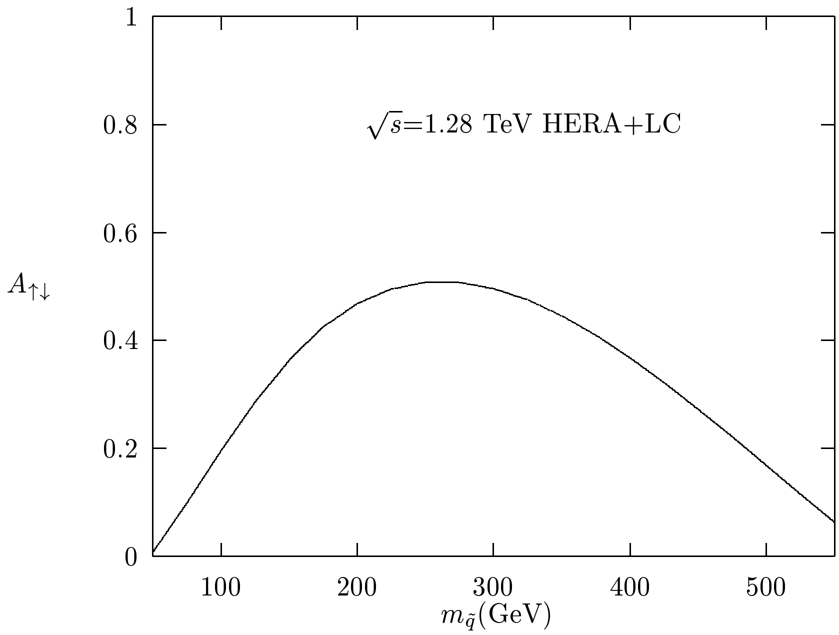
On the other hand the use of the polarized beams make it possible to look for the polarization asymmetries as a function of the squark masses. In Figs.2.(a-c) we have presented the results of the polarization asymmetry using the results of the up and down polarized proton beams. Asymmetry has been defined through the following relation

$$A_{\uparrow\downarrow} = \frac{\sigma_{R\uparrow} - \sigma_{R\downarrow}}{\sigma_{R\uparrow} + \sigma_{R\downarrow}} \tag{19}$$

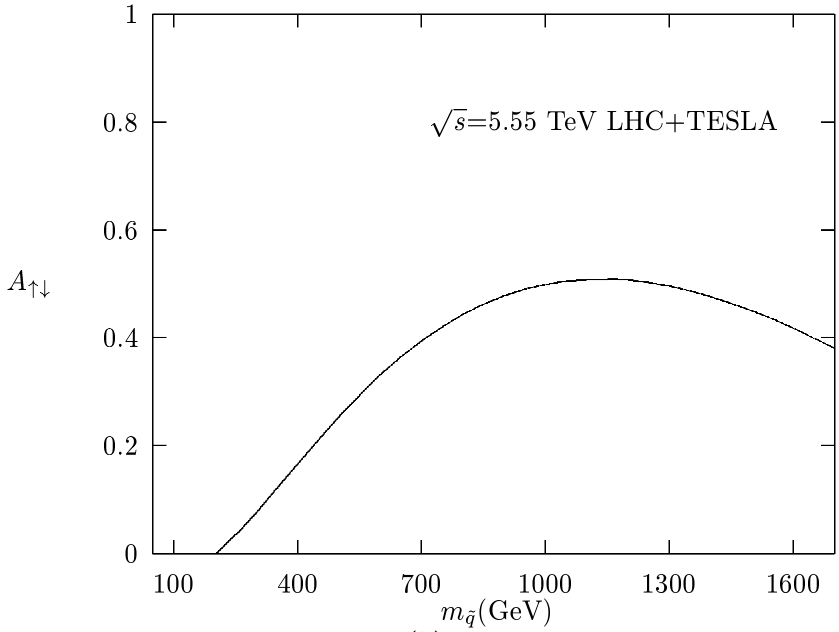
As can be seen from the Figs.2.(a-c) the asymmetry is sensitive to the squark mass which can be useful for determination of the mass parameter. Furthermore another asymmetry might be defined considering the opposite polarizations of the laser beam. Hence left-right asymmetry defined with respect to the laser beam as

$$A_{LR} = \frac{\sigma_{R\uparrow} - \sigma_{L\uparrow}}{\sigma_{R\uparrow} + \sigma_{L\uparrow}} \tag{20}$$

The results of the calculations are plotted in Fig.3 and a similar behaviour is seen.



(a)



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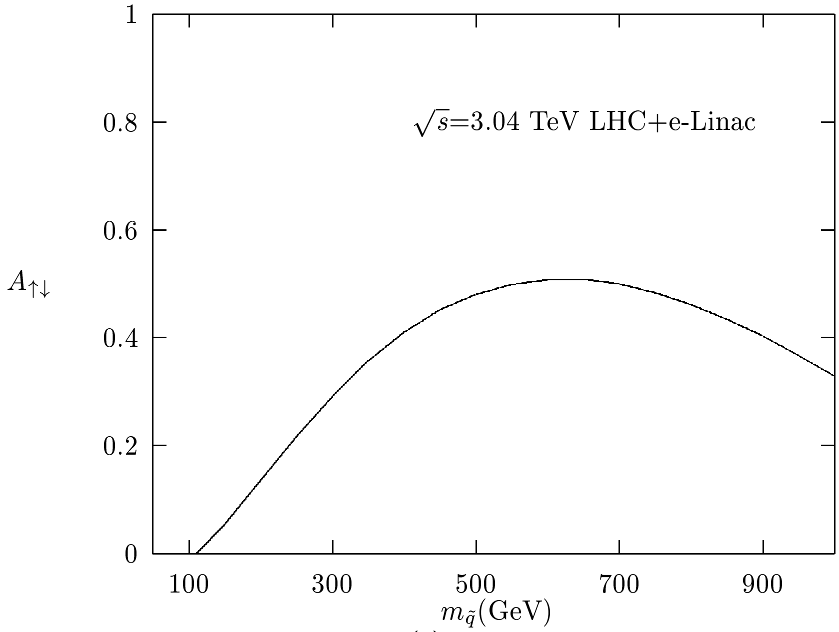


(c)

Figure 2. (a-c) Up-down asymmetry versus squark masses for different γp colliders.

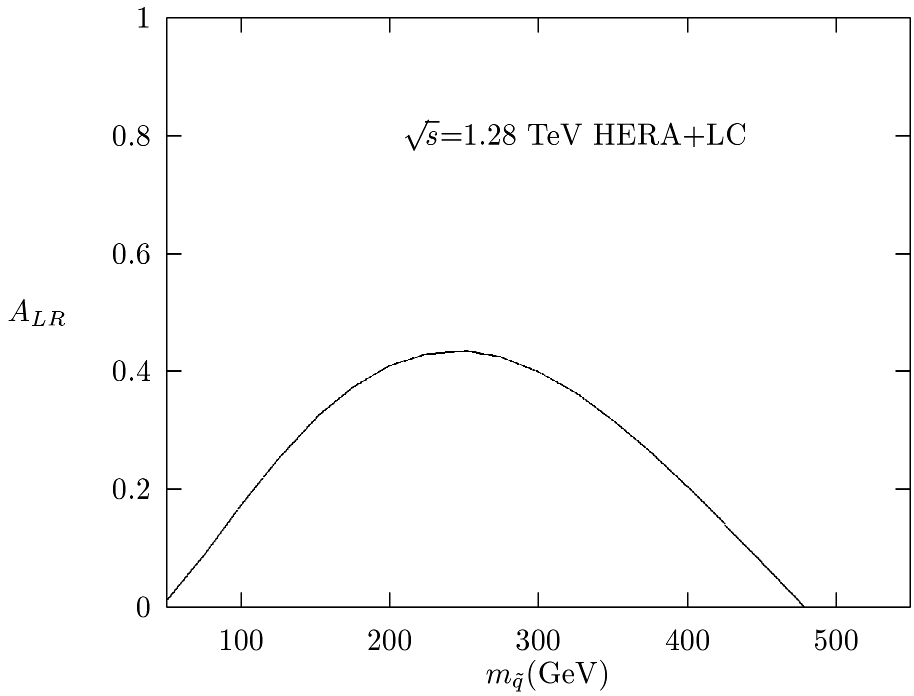


Figure 3. Left-right asymmetry versus squark mass for the HERA+LC γp collider.

2.2. Gluino-Squark Production

In this section, the subprocess $\gamma\, q \longrightarrow \tilde{q}\, \tilde{g}$ is considered taking into account the direct introduction of the photons with partons in the proton. The invariant amplitude for this subprocess is the sum of the terms corresponding to the s-channel quark exchange and u-channel squark exchange interactions. In order to take into consideration the polarization in the calculation of the differential cross-section we use the density matrices of the colliding beams here again. Density matrix for the quarks can be taken in the form of the massless spin 1/2 particles since the mass of quark has been ignored in the calculation of the invariant amplitude.

$$\rho^q = \frac{1}{2}\gamma p(1 \pm 2\lambda_q \gamma^5) \tag{21}$$

Here λ_q refers to the helicities of the quarks inside the proton and takes the values of $+1/2(-1/2)$ for the positive (or negative) helicite corresponding to the spin direction to the paralel (or antiparallel) of its momentum. The calculation of differential cross-section has been performed in the center of mass frame. One can easily obtain the total cross-section $\hat{\sigma}$ for the subprocess under consideration by integrating over $\hat{t}$:

$$\hat{\sigma}(m_{\widetilde{g}}, m_{\widetilde{q}}, \hat{s}, \xi_2, \lambda_q) = C\frac{1}{2}(1+2\lambda_q)\left[A(m_{\widetilde{g}}, m_{\widetilde{q}}, \hat{s}) + \xi_2 B(m_{\widetilde{g}}, m_{\widetilde{q}}, \hat{s})\right] \tag{22}$$

here C is a coefficient which includes coupling constants and color factor, ξ_2 is the helicity for the backscattered laser photon. For the subprocess cross-section $\hat{\sigma}(m_{\tilde{q}}, m_{\tilde{g}}, \hat{s}, \xi_2, \lambda_q)$ we can use the following short notations:

$$\begin{aligned}
\hat{\sigma}(\xi_2 = +1, \lambda_q = +\frac{1}{2}) &\equiv \hat{\sigma}_{++} \\
\hat{\sigma}(\xi_2 = -1, \lambda_q = +\frac{1}{2}) &\equiv \hat{\sigma}_{-+} \\
\hat{\sigma}(\xi_2 = +1, \lambda_q = -\frac{1}{2}) &\equiv \hat{\sigma}_{+-} = 0 \\
\hat{\sigma}(\xi_2 = -1, \lambda_q = -\frac{1}{2}) &\equiv \hat{\sigma}_{--} = 0
\end{aligned} \tag{23}$$

From Eq.(22) it can be easily seen that the last two relations in Eq.(23) vanish for $\lambda_q = -1/2$. In order to obtain the total cross-section for the process $\gamma p \to \tilde{q}\ \tilde{g}\ X$ one should perform the integration over the quark and photon distributions. After making the change of the variables ($\hat{s} = x_1 x_2 s$, $x_1 = x$, $x_2 = y$, $x_1 x_2 = \tau$) to pass to $s = s_{ep}$ from $\hat{s} = s_{\gamma q}$ we can take the limiting values as: $x_{\min} = \tau/0.83$, $x_{\max} = 1$, $\tau_{\min} = (m_{\tilde{g}} + m_{\tilde{q}})^2/s$, $\tau_{\max} = 0.83$.

Then one can write the total cross-section for the right circular polarized laser and spin-parallel proton beam polarized longitudinally as follows:

$$\begin{aligned}
\sigma_{R\uparrow} = \int_{\tau_{\min}}^{0.83} d\tau \int_{\tau/0.83}^{1} \frac{dx}{x} \Big\{ P \Big[& f_+^{\gamma}(\frac{\tau}{x}) f_{+/\uparrow}^{q}(x)\hat{\sigma}_{++} + f_+^{\gamma}(\frac{\tau}{x}) f_{-/\uparrow}^{q}(x)\hat{\sigma}_{+-} \Big] \\
&+ (1-P) \Big[f_+^{\gamma}(\frac{\tau}{x}) f_{+/\downarrow}^{q}(x)\hat{\sigma}_{+-} + f_+^{\gamma}(\frac{\tau}{x}) f_{-/\downarrow}^{q}(x)\hat{\sigma}_{++} \Big] \Big\}
\end{aligned} \tag{24}$$

The above expression can be rearranged by considering the distribution of the valance quark (u-type) inside the proton and written in the form of:

$$\sigma_{R\uparrow} = \int_{\tau_{\min}}^{0.83} d\tau \int_{\tau/0.83}^{1} \frac{dx}{x} \left\{ f_+^{\gamma}(\frac{\tau}{x}) u_v^{+}(x)\hat{\sigma}_{++} \right\} \tag{25}$$

where u_v^{+}, u-type valance quark distribution with the positive helicity is defined by the sum of the nonpolarized and difference polarized quark distributions

$$u_v^{+}(x) = \frac{1}{2}(u_{np} + \triangle u_{pol}). \tag{26}$$

After inserting this expression into the Eq.(25) then it can be written as

$$\sigma_{R\uparrow} = \int_{\tau_{\min}}^{0.83} d\tau \int_{\tau/0.83}^{1} \frac{dx}{x} \left\{ f_{+}^{\gamma}(\frac{\tau}{x})\frac{1}{2}(u_{np} + \triangle u_{pol})\hat{\sigma}_{++} \right\} \tag{27}$$

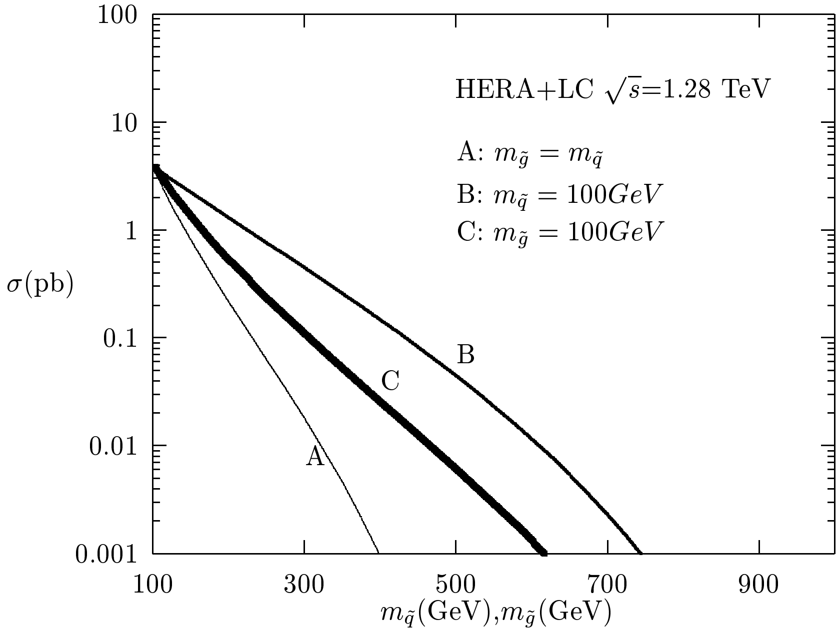
where $f_{\pm}^{\gamma}$ is the energy spectrum of the backscattered laser photons which is defined before. In the numerical integration for the helicity of the backscattered laser photon, the following relation is considered [Borden **et al.** in ref.1]:

$$\xi_2(\lambda_0, \lambda_e, y) = \frac{\lambda_0(1-2r)[1-y+1/(1-y)] + \lambda_e r\zeta[1+(1-y)(1-2r)^2]}{[1-y+1/(1-y) - 4r(1-r) - \lambda_0\lambda_e r\zeta(2r-1)(2-y)]} \tag{28}$$

Here λ_0, λ_e are the helicities of the first laser photon and the linac electron, $r = y/\zeta(1-y)$ and $\zeta = 4\omega_0 E_e/m_e^2 = 4.8$ corresponding to the optimum value of $y_{max} = 0.83$. The polarized and unpolarized valance quark distributions are taken from [15].

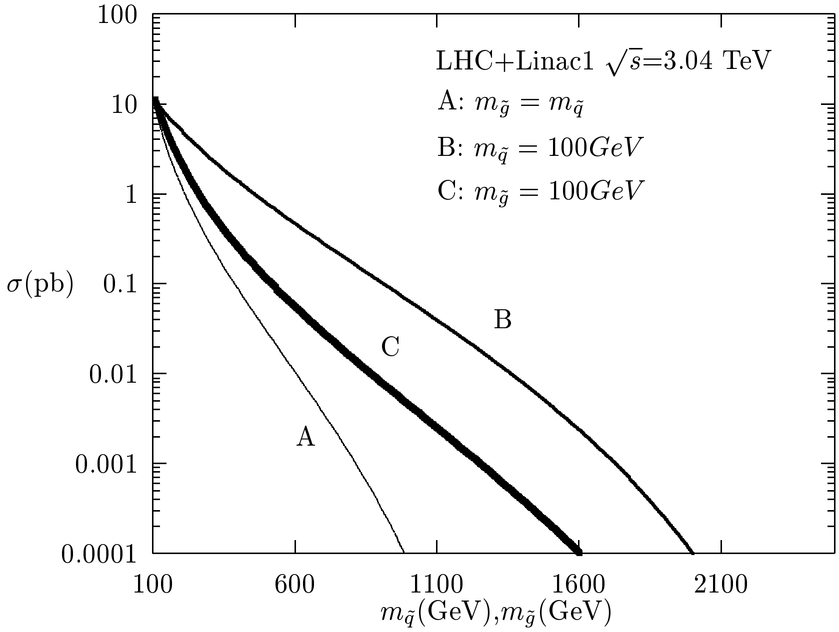
$$u_{np}(x) = 2.751x^{-0.412}(1-x)^{2.69} \tag{29}$$
$$\triangle u_{pol}(x) = 2.139x^{-0.2}(1-x)^{2.4} \tag{30}$$

After the numerical calculations we get the production cross sections for the SUSY particles and show the dependence of the total cross sections on the masses of the SUSY particles for various proposed γp colliders in Figs.4.(a-c) and Figs.5.(a-c). The upper mass limits for SUSY particle can easily be found from the figures by using the luminosities given in Table 1. These values are calculated by taking 100 events per running year as observation limit for SUSY particle and tabulated in Table 2 . In Figs.6.(a-c) we have presented the results of the polarization asymmetry with respect to the left-right polarized laser beams.



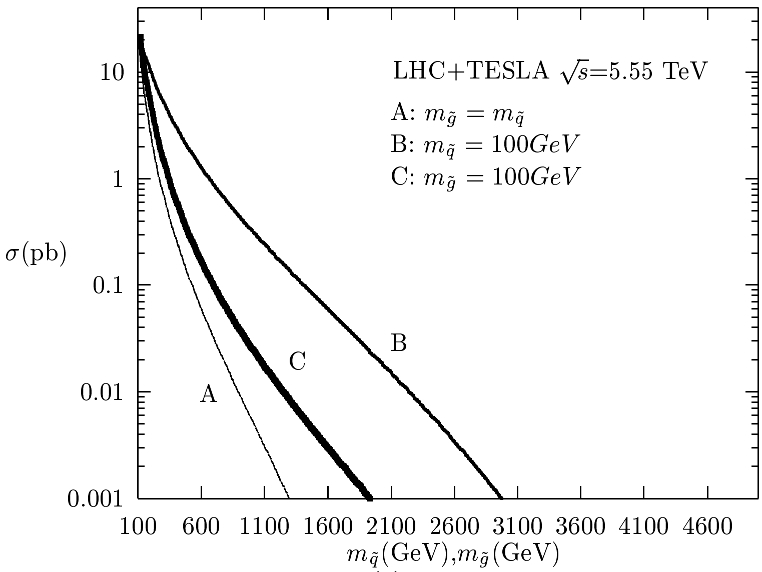
HERA+LC $\sqrt{s}$=1.28 TeV
A: $m_{\tilde{g}} = m_{\tilde{q}}$
B: $m_{\tilde{q}} = 100GeV$
C: $m_{\tilde{g}} = 100GeV$
A
B
C
σ(pb)
$m_{\tilde{q}}$(GeV),$m_{\tilde{g}}$(GeV)

(a)



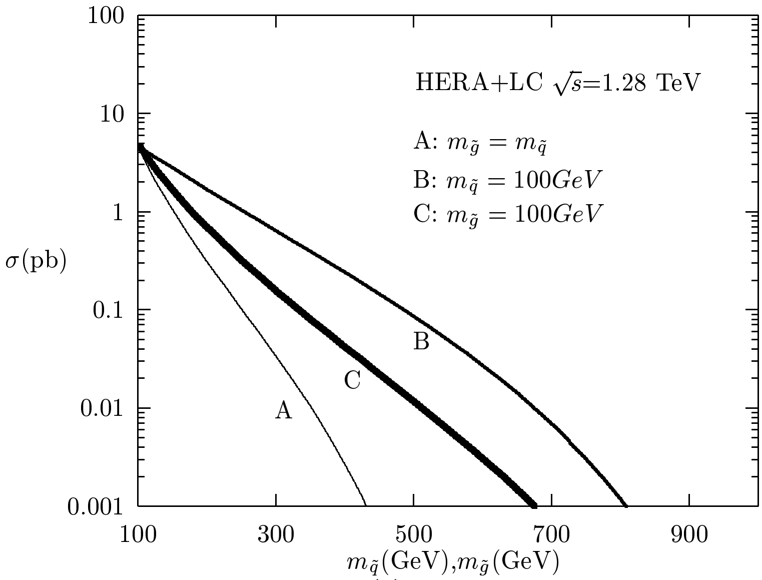
LHC+Linac1 $\sqrt{s}$=3.04 TeV
A: $m_{\tilde{g}} = m_{\tilde{q}}$
B: $m_{\tilde{q}} = 100GeV$
C: $m_{\tilde{g}} = 100GeV$
A
B
C
σ(pb)
$m_{\tilde{q}}$(GeV),$m_{\tilde{g}}$(GeV)

(b)

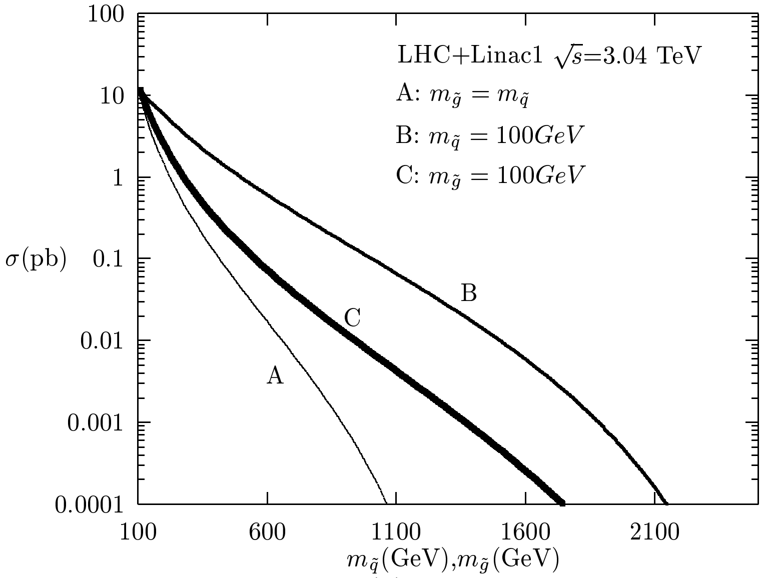


(c)

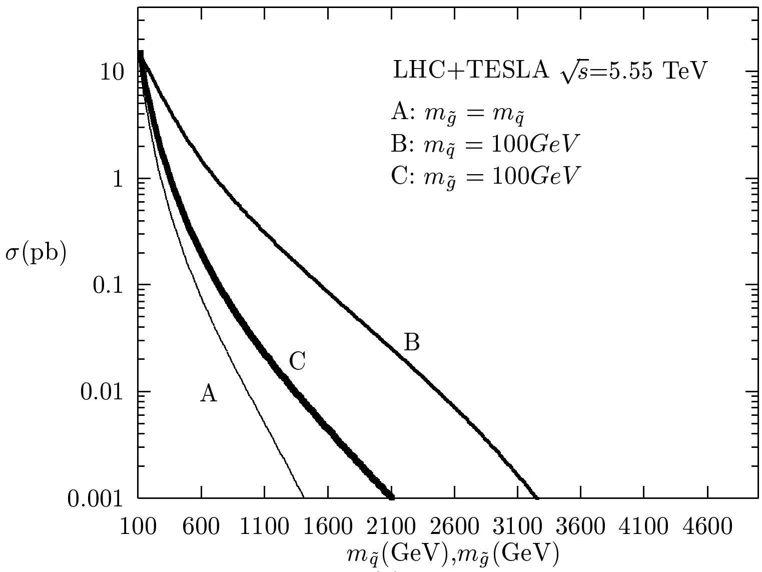
Figure 4. (a-c) Production cross sections for gluino and squarks as a function of their masses for various colliders. Each figure corresponds to the right polarized laser and spin-parallel proton beam longitudinally.



(a)

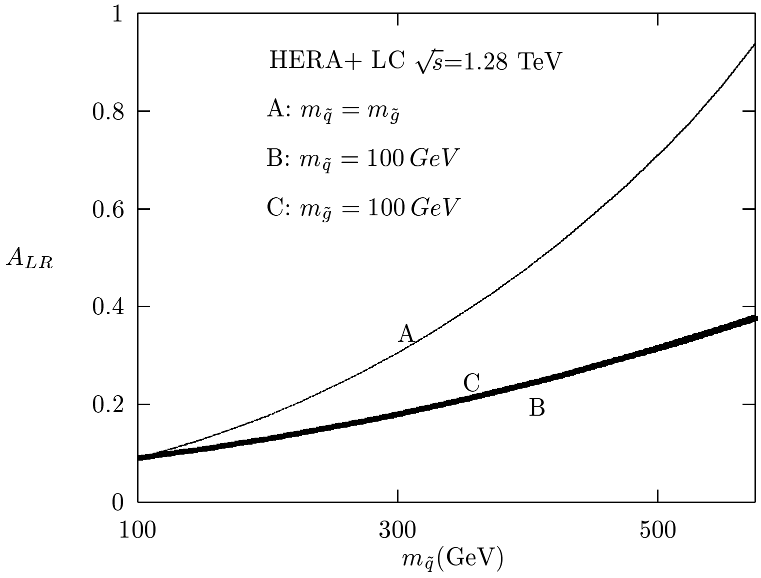


(b)

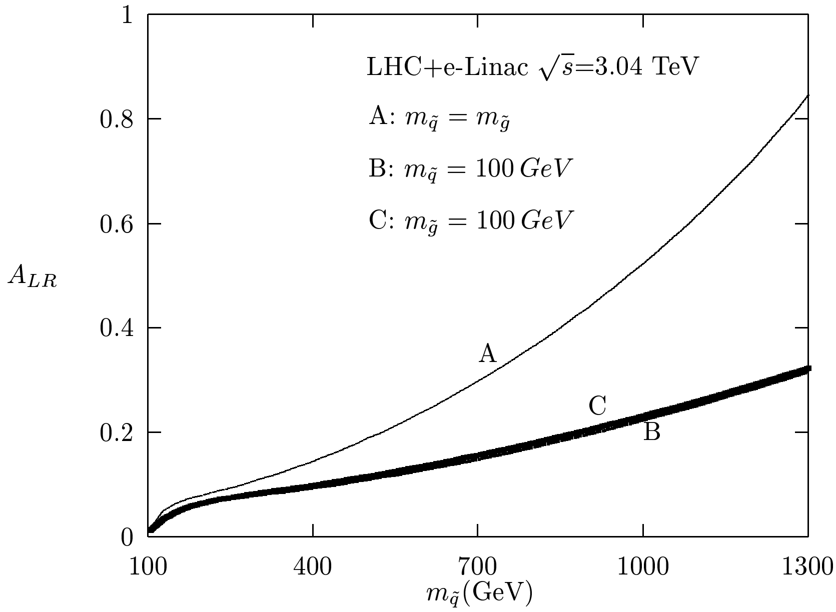


(c)

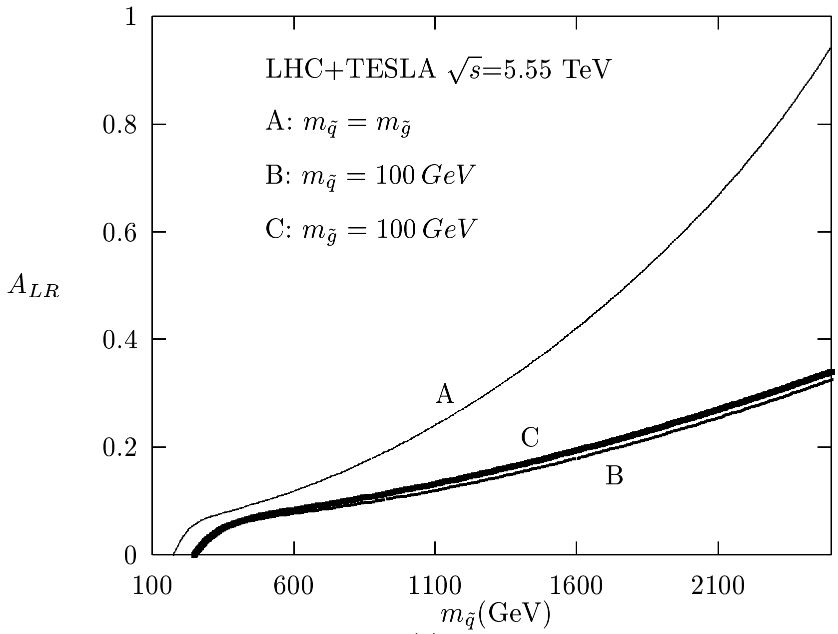
Figure 5. (a-c) Production cross sections for gluino and squarks as a function of their masses for various colliders. Each figure corresponds to the left polarized laser and spin-parallel proton beam longitudinally.


HERA+ LC $\sqrt{s}$=1.28 TeV
A: $m_{\tilde{q}} = m_{\tilde{g}}$
B: $m_{\tilde{q}} = 100\,GeV$
C: $m_{\tilde{g}} = 100\,GeV$
A_{LR}
A
C
B
0
0.2
0.4
0.6
0.8
1
100
300
500
$m_{\tilde{q}}$(GeV)

(a)


LHC+e-Linac $\sqrt{s}$=3.04 TeV
A: $m_{\tilde{q}} = m_{\tilde{g}}$
B: $m_{\tilde{q}} = 100\,GeV$
C: $m_{\tilde{g}} = 100\,GeV$
A_{LR}
A
C
B
0
0.2
0.4
0.6
0.8
1
100
400
700
1000
1300
$m_{\tilde{q}}$(GeV)

(b)



(c)

Figure 6. (a-c) Left-right asymmetry versus SUSY particle masses for different γp colliders.

3. Signature and Conclusion

One characteristic feature of the R-parity conserving supersymmetric processes is the large missing energy. Usually the photino and sneutrino are taken as the lightest SUSY particles and will not be observed. The possible decay modes of squarks and gluinos depend on the mass spectrum and on the coupling constants. The squark will mainly decay into a quark and a photino. There are also possible decays of the squark into a wino or a zino with the less branching ratios. One possibility of the decay of zino is the decay into a neutrino and a sneutrino. Therefore the signature for the process $\gamma p \rightarrow \tilde{q}\tilde{\bar{q}}X$ will be in general multijets + lepton(s) + large missing energy and missing p_T. The gluino will decay into a squark and antiquark. According to the results of the futher decays, the signature for the process $\gamma p \rightarrow \tilde{q}\tilde{g}X$ might be in general multijets + large missing energy and missing p_T. The definite polarization asymmetries associated with the missing energy and momentum may help in separating these events from the backgrounds.

The production of the squark pairs in $ep \rightarrow \gamma^* g \rightarrow \tilde{q}\tilde{\bar{q}}$ collisions via the quasi-real photon gluon fusion were studied before [12, 13]. However in these studies Weizsacker-Williams approximation has been used for the quasi-real photon distribution $f_{\gamma/e}$. Since the WW-spectrum is much softer than the real γ spectrum the discovery mass limits for the squarks in our case turn out to be much higher than the conventional ep-colliders. The results of Section B indicate that these limits for $\tilde{q}\tilde{g}$ production is $0.17TeV$ for equal mass case.

Finally our analysis shows that the future γp colliders can have considerable capacities in addition to the well known pp and e^+e^- colliders in the investigation of supersymmetric particles. We see that the range of squark masses that can be explored at various γp-machines (200 GeV - 0.85 TeV) are higher than the corresponding values at standard type ep-colliders (20 GeV - 80 GeV for HERA). Several LHC studies have shown that the reach for squarks will be greater than 1 TeV. But clearer backgrouds in a gamma-proton collider can be considered to be an advantageous feature in extracting supersymmetric signals.

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