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GLUINO-SQUARK PRODUCTION IN POLARIZED γp COLLISIONS

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We discuss the production of gluino-squark in recently proposed γp colliders taking into consideration the polarizations of the colliding beams. The discovery mass limits for the squarks and gluinos are presented and the results are compared with the literature.

I. INTRODUCTION

Supersymmetry seems to be one of the most promising candidates for TeV scale physics beyond the SM due to having interesting motivations, such as providing the solution of the fine-tunning problem and of the hierarchy problem of grand unification [1]. The minimal supersymmetric extension of the standart model leads necessarily to doubling of the usual particle spectrum; every particle has a superpartner differing in spin by a half unit and needs two Higgs doublets to give mass to both up and down quarks. It also predicts that the SUSY partners of the known particles have masses of not more than 1 TeV. The production and the detection of SUSY particles have been extensively studied in hadron-hadron colliders, ep-machines and e^+e^- accelerators, but the experimental evidence has not been found yet. These machines indicate that the masses of squarks and gluinos are $m_{\tilde{q},\tilde{g}} \geq 130 GeV$. On the other hand, the experiments at all possible types of colliding beams should be considered to explore the new physics at the TeV scale. Consequently higher energy scale should be probed and it is desirable to reach the TeV scale at a constituent level. Although 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, future γp colliders can have promising capasities to search SUSY too.

Recently, 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 [2]. 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 [3]. 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.2]. For the physics program at γe and $\gamma\gamma$ machines see [4,5]. Recently different physics phenomena which can be investigated at γp colliders have been considered in a number of papers [6-8]. It seems that these machines may open new possibilities for the investigations of the Standard Model and beyond it. For a review see [9].

In the following section we discuss the cross-section for gluino-squark production process at TeV scale polarized γp colliders and indicate the discovery mass limits for this sparticles under consideration. We also present the polarization asymmetries as a function of squark or gluino masses. Several SUSY production processes such as $\gamma p \to \tilde{q}\tilde{w}X$, $\gamma p \to \tilde{w}\tilde{w}X$, $\gamma p \to \tilde{q}\tilde{q}X$, $\gamma p \to \tilde{q}\tilde{\gamma}X$ (or $\tilde{q}\tilde{z}$) and $\gamma p \to \tilde{q}\tilde{g}X$ have already been discussed [7]. Also scalar leptoquark productions at TeV energy γp colliders have been investigated [8].

II. GLUINO-SQUARK PRODUCTION

In this section, the subprocess $\gamma q \longrightarrow \tilde{q}\,\tilde{g}$ is considered taking into account the direct interaction 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. For polarized and unpolarized cases the density matrices of photon is given as follows:

$$\rho^{(\gamma)}_{\mu\mu'} = -\frac{1}{2}g_{\mu\mu'} \qquad \textit{unpolarized case} \tag{1}$$

$$\rho^{(\gamma)}_{\mu\mu'} = \frac{1}{2}(1+\vec{\xi}\cdot\vec{\sigma})_{ab}e^{(a)}_{\mu}e^{(b)}_{\mu'} \quad \textit{polarized case} \tag{2}$$

where $\vec{\sigma} = (\sigma_1, \sigma_2, \sigma_3)$ are the usual Pauli matrices and $\vec{\xi} = (\xi_1, \xi_2, \xi_3)$ are Stokes parameters of the backscattered laser photon. In our calculations we take into consideration only circular polarizations that is defined by ξ_2. For the right (left) circular polarization, ξ_2 take the value of $+1(-1)$. $e^{(a)}_{\mu}$ $(a = 1, 2)$ are the polarization unit 4-vectors which are orthogonal to each other and to the momenta of the colliding particles. 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.

$$\rho^{q} = \frac{1}{2}\gamma p(1 \pm 2\lambda_q\gamma^5) \tag{3}$$

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) helicity 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 $\hat{t}$:

$$\hat{\sigma}(m_{\tilde{g}}, m_{\tilde{q}}, \hat{s}, \xi_2, \lambda_q) = C\frac{1}{2}(1+2\lambda_q)\left[A(m_{\tilde{g}}, m_{\tilde{q}}, \hat{s}) + \xi_2 B(m_{\tilde{g}}, m_{\tilde{q}}, \hat{s})\right] \tag{4}$$

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:

$$\begin{aligned}
\hat{\sigma}(\xi_2 = +1, \lambda_q = +\tfrac{1}{2}) &\equiv \hat{\sigma}_{++} \\
\hat{\sigma}(\xi_2 = -1, \lambda_q = +\tfrac{1}{2}) &\equiv \hat{\sigma}_{-+} \\
\hat{\sigma}(\xi_2 = +1, \lambda_q = -\tfrac{1}{2}) &\equiv \hat{\sigma}_{+-} = 0 \\
\hat{\sigma}(\xi_2 = -1, \lambda_q = -\tfrac{1}{2}) &\equiv \hat{\sigma}_{--} = 0
\end{aligned} \tag{5}$$

From Eq.(4) it can be easily seen that the last two relations in Eq.(5) vanish for $\lambda_q = -1/2$. In order to obtain the total cross-section for the process $\gamma p \rightarrow \tilde{q}\,\tilde{g}\,X$ 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:

$$\begin{aligned}
\sigma_{R\uparrow} = \int_{\tau_{\min}}^{0.83} d\tau \int_{\tau/0.83}^{1} \frac{dx}{x} \Big\{ P\Big[f^{\gamma}_{+}(\frac{\tau}{x}) f^{q}_{+/\uparrow}(x)\hat{\sigma}_{++} + f^{\gamma}_{+}(\frac{\tau}{x}) f^{q}_{-/\uparrow}(x)\hat{\sigma}_{+-}\Big] \\
+ (1-P)\Big[f^{\gamma}_{+}(\frac{\tau}{x}) f^{q}_{+/\downarrow}(x)\hat{\sigma}_{+-} + f^{\gamma}_{+}(\frac{\tau}{x}) f^{q}_{-/\downarrow}(x)\hat{\sigma}_{++}\Big]\Big\}
\end{aligned} \tag{6}$$

where P is the polarization percetage of spin-parallel protons in the beam and $f^{\gamma}_{\pm}(y)$ is the energy spectrum of the laser photons which is given as follows [Ginzburg et al. in ref.2]:

$$f_{\pm}^{\gamma}(y) = \frac{1}{\sigma}\frac{2\pi\alpha^2}{\zeta m_e^2}\Big[\ 1 - y + \frac{1}{1-y} - \frac{4y}{\zeta(1-y)} + \frac{4y^2}{\zeta^2(1-y)^2}$$
$$- \lambda_e\lambda_\gamma \frac{y(2-y)}{(1-y)}\left(\frac{2y}{\zeta(1-y)} - 1\right)\Big] \tag{7}$$

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 backscattered laser photon helicities respectively and σ is the total Compton cross section:

$$\sigma = \sigma^0 + \lambda_e\lambda_\gamma\sigma^1 \tag{8}$$

$$\sigma^0 = \frac{\pi\alpha^2}{\zeta m_e^2}\left[(2 - \frac{8}{\zeta} - \frac{16}{\zeta^2})ln(\zeta + 1) + 1 + \frac{16}{\zeta} - \frac{1}{(\zeta+1)^2}\right] \tag{9}$$

$$\sigma^1 = \frac{\pi\alpha^2}{\zeta m_e^2}\left[(2 + \frac{4}{\zeta})ln(\zeta + 1) - 5 + \frac{2}{(\zeta+1)} - \frac{1}{(\zeta+1)^2}\right] \tag{10}$$

In the numerical integration the helicity of the backscattered laser photon, λ_γ is giving by the following expresion [Borden et. al. in ref.2]:

$$\xi_2(\lambda_0, \lambda_e, y) = \frac{\lambda_0(1-2r)[1-y+1/(1-y)] + \lambda_e r\zeta[1+(1-y)(1-2r)^2]}{[1-y+1/(1-y) - 4r(1-r) - \lambda_0\lambda_e r\zeta(2r-1)(2-y)]}. \tag{11}$$

Here λ_0, λ_e are the helicities of the first laser photon and the linac electron, $r = y/\zeta(1-y)$ and $\zeta = 4.8$ corresponding to the optimum value of $y_{max} = 0.83$.

The total cross-section expression in Equ.(6) can be rearranged by considering the distribution of the valance quark (u-type) inside the proton and written in the form of:

$$\sigma_{R\uparrow} = \int_{\tau_{min}}^{0.83} d\tau \int_{\tau/0.83}^{1} \frac{dx}{x}\left\{f_+^{\gamma}(\frac{\tau}{x})u_v^+(x)\hat{\sigma}_{++}\right\} \tag{12}$$

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

$$u_v^+(x) = \frac{1}{2}(u_{np} + \Delta u_{pol}). \tag{13}$$

After inserting this expression into the Eq.(12) then it can be written as

$$\sigma_{R\uparrow} = \int_{\tau_{min}}^{0.83} d\tau \int_{\tau/0.83}^{1} \frac{dx}{x}\left\{f_+^{\gamma}(\frac{\tau}{x})\frac{1}{2}(u_{np} + \Delta u_{pol})\hat{\sigma}_{++}\right\}. \tag{14}$$

For the polarized and unpolarized valance quark distributions in the above expression, the following relations have been used taking from [10].

$$u_{np}(x) = 2.751x^{-0.412}(1-x)^{2.69} \tag{15}$$

$$\Delta u_{pol}(x) = 2.139x^{-0.2}(1-x)^{2.4}. \tag{16}$$

After the numerical calculations we get the production cross sections for the gluino-squark process and show the dependence of the total cross sections on the masses of the SUSY particles for various proposed γp colliders in Figs.1(a-c) and Figs.2(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 the same table.

Furthermore it is possible to look for the polarization asymmetries as a function of the sparticle mass which can be useful for determination of the mass parameter. Asymmetry with respect to the polarization cases of the laser beam is defined by the following relation

$$A_{LR} = \frac{\sigma_{R\uparrow} - \sigma_{L\uparrow}}{\sigma_{R\uparrow} + \sigma_{L\uparrow}}. \tag{17}$$

One can also consider the another asymmetry defined by using the results of the up and down polarized proton beams as follow:

$$A_{\uparrow\downarrow} = \frac{\sigma_{R\uparrow} - \sigma_{R\downarrow}}{\sigma_{R\uparrow} + \sigma_{R\downarrow}}. \tag{18}$$

In Figs.3(a-c) we have presented the results of the polarization asymmetry with respect to the left-right polarized laser beams.

III. 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 gluino will decay into a squark and antiquark. 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. According to the results of decay channels, 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.

In conclusion, 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.

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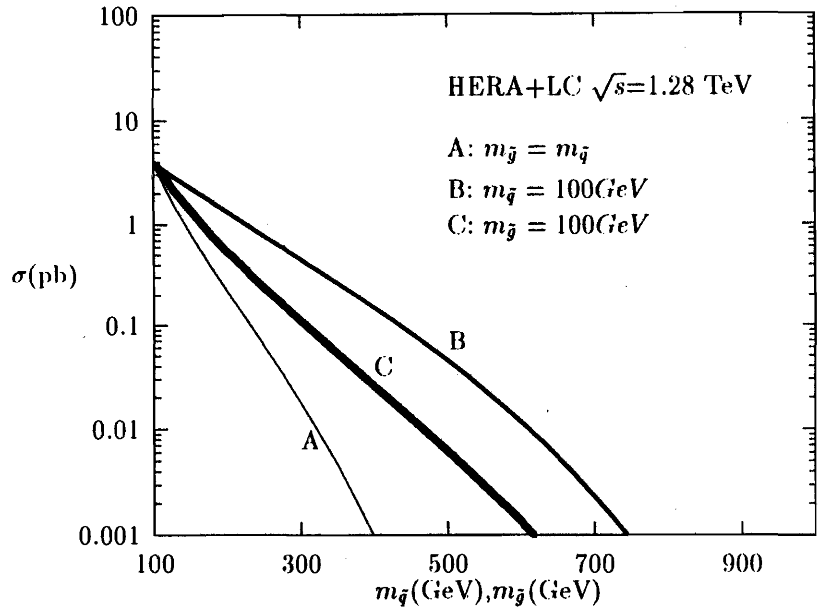
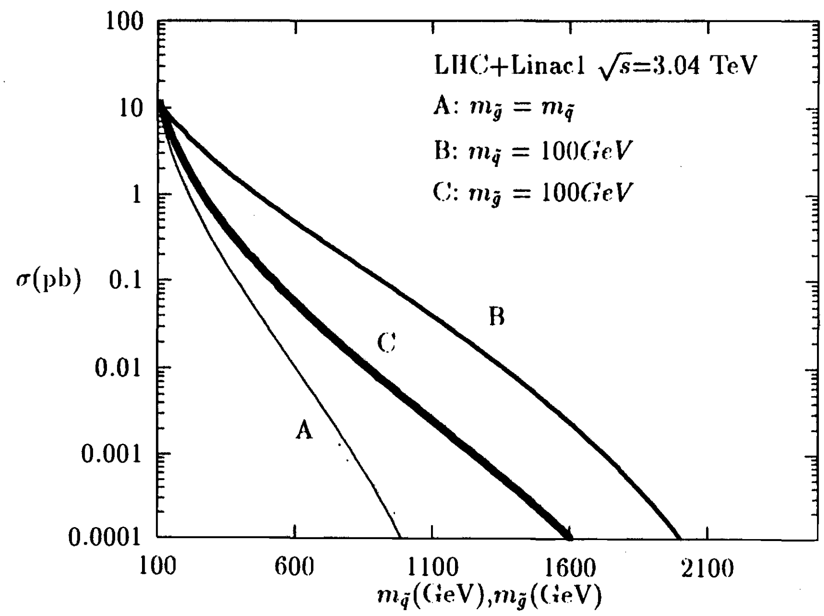
[1] H.E.Haber and G.L.Kane,Phys.Rep.**C117**,(1986)75
H.P.Nilles, Phys.Rep.**C110**,(1984)1
C. H.Llewellyn-Smith,Phys.Rep.**C105**,(1984)53
D.V.Nanopoulos,Rep.Prog.Phys.**49**,(1986)61.
[2] R.N.Milburn, Phys.Rev.Lett.**10**(1963)75
I.F.Ginzburg et al.,Piz'ma ZhETF(1981)47
I.F.Ginzburg et al.,Nucl.Instrum. and Meth.**205**(1983)47
I.F.Ginzburg et al.,Nucl.Instrum. and Meth.**219**(1984)5
V.I.Telnov, Nucl.Instrum.and Meth.**A294**(1990)72
D.L.Borden,D.A.Bauer and D.O.Caldwell, SLAC preprint SLAC-5715 Stanford (1992)
S.F.Sultansoy, ICTP preprint IC/89/409,Trieste(1989).
Z.Z.Aydin, V.A.Maniyev and S.F.Sultansoy,Particle World**4**(1994)22
Z.Z.Aydin, A.K.Çiftçi and S.Sultansoy, Nucl.Instrum.and Meth.**A351**(1994)261.
Z.Z.Aydin, A.K.Çiftçi and S.Sultansoy, Turkish J.Phys.**19**(1995)781
A.K.Çiftçi, S.Sultansoy, Ş. Türköz and Ö. Yavaş, Nucl.Instrum.and Meth.**A365**(1995)317.
[3] S.I.Alekhin et al., IHEP preprint 87-48 (1987)
S.F.Sultansoy, *ibid*
Z.Z.Aydin, A.K.Çiftçi and S.Sultansoy, *ibid*
Z.Z.Aydin, A.K.Çiftçi and S.Sultansoy, Turkish J.Phys.**19**(1995)773
P.Grosse-Wiesmann, Nucl.Instrum. and Meth.**A274**(1989)21
M.Tigner, B.Wiik and F.Willeke, Proc.Part.Acc.Conf. San Fransisco (1991) v.5,p.2910
R.Brinkmann and M.Dohlus (to be published).
[4] J.A.Grifols and R.Pascual, Phys.Lett.**B135**(1984)319
E.Boos et al., Phys.Lett.**B173**(1991)273
E.Boos et al., DESY preprint 91-114 Hamburg(1991)
J.E.Cieza Montalvo and O.J.P.Eboli, Phys.Rev.**D47**(1993)837
M.Nadeau and D.London,Phys.Rev.**D47**(1993)3742.
[5] A.Goto and T.Kon, Europhys.Lett.**13**(1990)211
T.Kon and A.Goto, Phys.Lett.**B295**(1992)324
F.Cuypers et al.,Nucl.Phys.**B383**(1992)45
A.Goto and T.Kon, Europhys.Lett.**19**(1992)575
H.Konig and K.A.Peterson, Phys.Lett.**B294**(1992)110
F.Cuypers et al.,Nucl.Phys.**B409**(1993)144
T.Kon,Proc.of Fourth Workshop of JLC,KEK p.47 (1993).

[6] S.I.Alekhin et al.,Int.J.of Mod.Phys. **A6**,(1991)23
E.Boos et al., Proc. 26th Moriond Conf.p.501 (1991)Moriond, France
G.Jikia,Nucl.Phys.**B333**,(1990)317.
[7] W.Büchmüller and Z.Fodor, Phys.Lett.**B316**,(1993)510.
A.T.Alan, Z.Z.Aydin and S.Sultansoy, Phys.Lett.**B327**(1994)70
A.T.Alan, S.Atağ, and Z.Aydin, J.Phys.G.**20**(1994)1399
A.Alan et al.,Turkish J.Phys.**19**(1995)796
A.U.Yılmazer, A.T.Alan and A.Kandemir, Turkish J.Phys.**20**(1996)1034
A.Kandemir and A.U.Yılmazer, Phys.Lett.**B385**(1996)143.
[8] S.Atağ, A.Çelikel and S.Sultansoy , Phys.Lett.**B326**,(1994)185
S.Atağ and O.Çakır, Phys.Rev.**D49**,(1994)5769
O.Çakır and S.Atağ, J.Phys.G.**21**(1995)1189
S.Atağ et al., Turkish J.Phys.**19**(1995)805.
[9] Z.Z.Aydin et al.,Int.J.Mod.Phys.**A11**,(1996)2019.
[10] G.Alterelli and W.J.Stirling, Particle World**1**(1989)40
A.Schafer,Phys.Lett. **B208**(1988)175.



HERA+LC $\sqrt{s}$=1.28 TeV
A: $m_{\tilde{g}} = m_{\tilde{q}}$
B: $m_{\tilde{q}} = 100GeV$
C: $m_{\tilde{g}} = 100GeV$
σ(pb)
100
10
1
0.1
0.01
0.001
100
300
500
700
900
$m_{\tilde{q}}$(GeV),$m_{\tilde{g}}$(GeV)
A
B
C

Fig.1a



LHC+Linac1 $\sqrt{s}$=3.04 TeV
A: $m_{\tilde{g}} = m_{\tilde{q}}$
B: $m_{\tilde{q}} = 100GeV$
C: $m_{\tilde{g}} = 100GeV$
σ(pb)
100
10
1
0.1
0.01
0.001
0.0001
100
600
1100
1600
2100
$m_{\tilde{q}}$(GeV),$m_{\tilde{g}}$(GeV)
A
B
C

Fig.1b

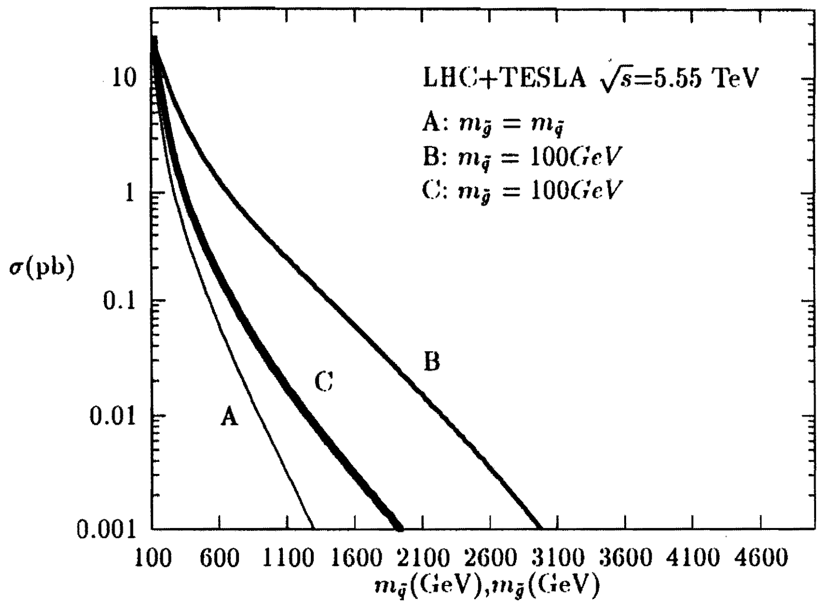


Fig.1c

FIG. 1. (a-c) Production cross sections for gluino-squark as a function of their masses for various colliders. Each figure corresponds to right circular polarized laser and spin-parallel proton beam polarized longitudinally.

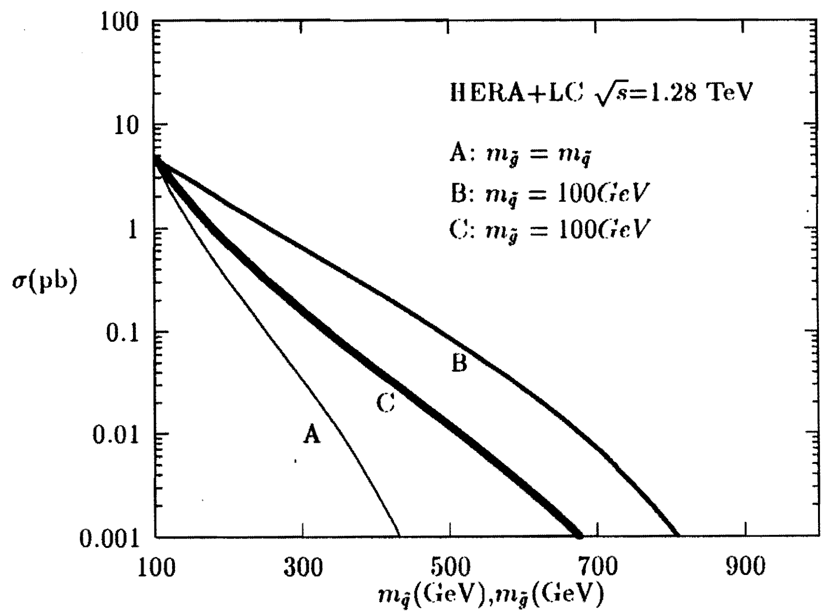


Fig.2a

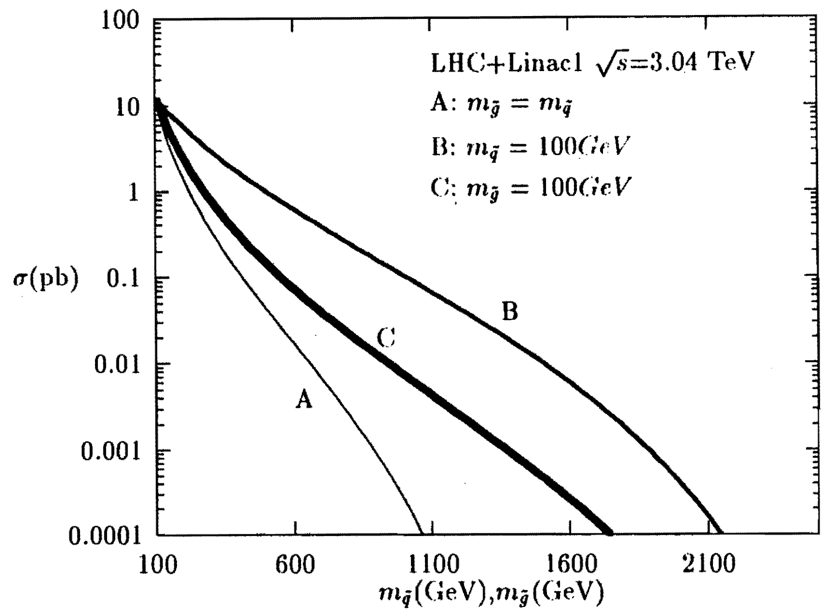


Fig.2b

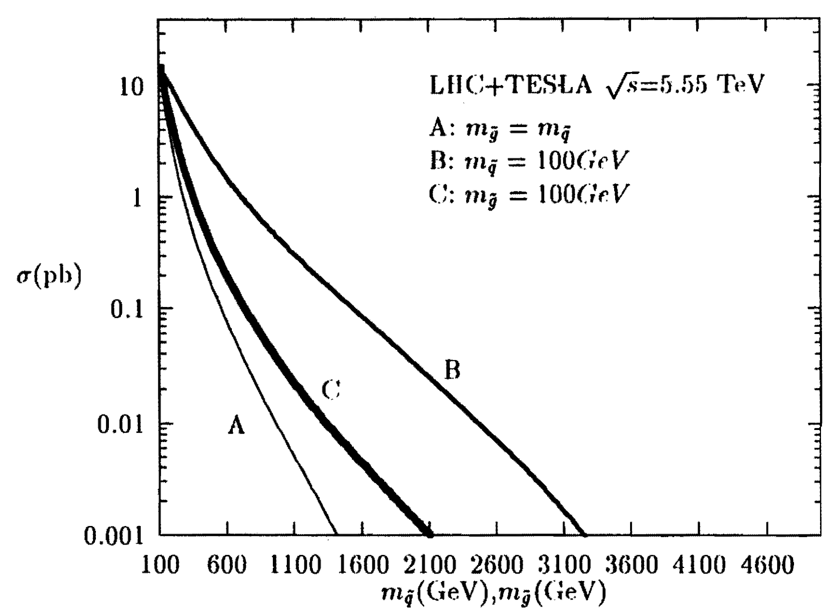
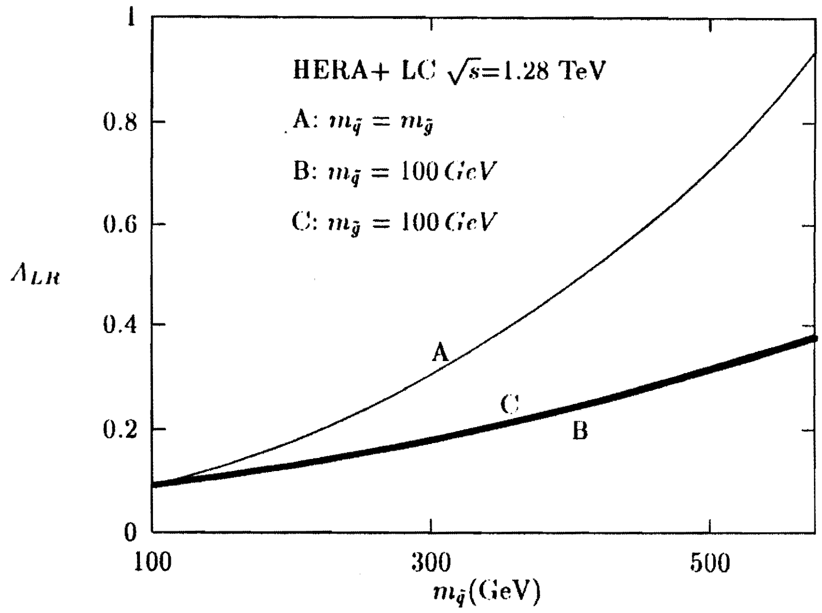


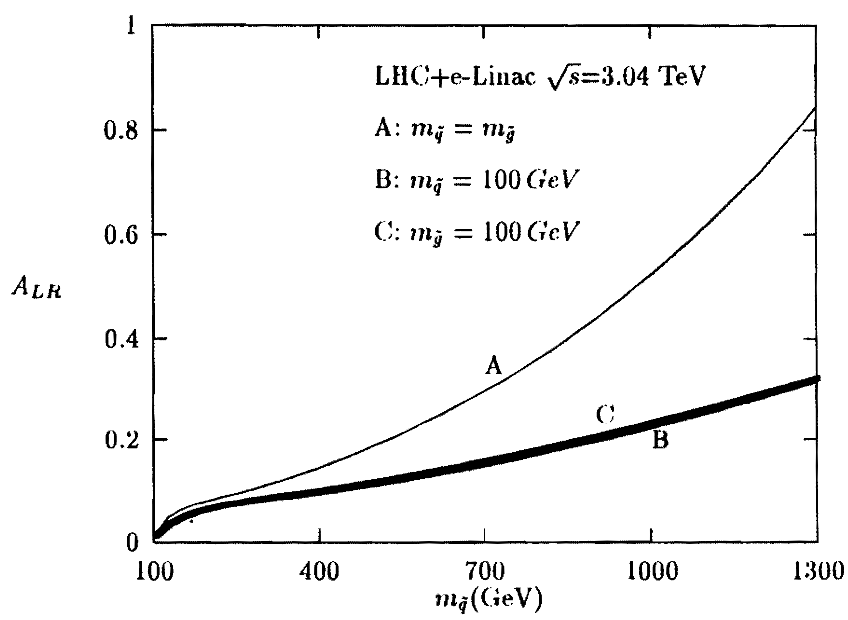
Fig.2c

FIG. 2. (a-c) Production cross sections for gluino and squarks as a function of their masses for various colliders. Each figure corresponds to right circular polarized laser and spin-parallel proton beam polarized 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}
$m_{\tilde{q}}$(GeV)
A
B
C
0
0.2
0.4
0.6
0.8
1
100
300
500

Fig.3a



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}
$m_{\tilde{q}}$(GeV)
A
B
C
0
0.2
0.4
0.6
0.8
1
100
400
700
1000
1300

Fig.3b

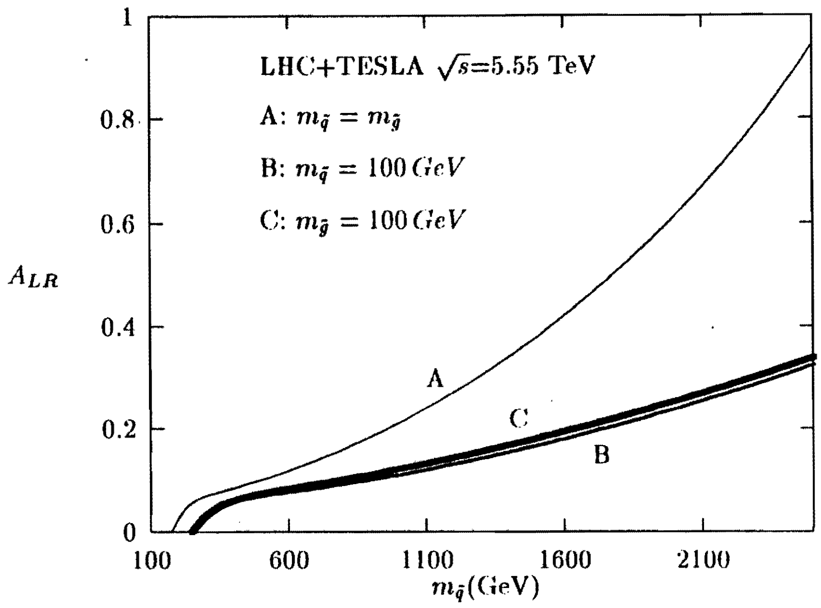


Fig.3c

FIG. 3. (a-c) Left-right asymmetry versus sparticle masses for different γp colliders

TABLE I. Parameters of different γp colliders and discovery mass limits for scalar quarks and gluinos. (Note: $\sqrt{s_{\gamma p}}^{max} = 0.91\sqrt{s_{ep}}$)

Machines	$\sqrt{s_{ep}}$ (TeV)	$\mathcal{L}_{\gamma p}$ $(10^{30} cm^{-2} s^{-1})$	$m_{\tilde u} = m_{\tilde g}$ (TeV)	$m_{\tilde u} = 0.10$ $m_{\tilde g}$ (TeV)	$m_{\tilde g} = 0.10$ $m_{\tilde u}$ (TeV)
HERA+LC	1.28	25	0.17	0.32	0.21
LHC+TESLA	5.55	500	0.77	1.90	1.05
LHC+e-Linac	3.04	500	0.53	1.22	0.75