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GLUINO PAIR PRODUCTION IN ELECTRON-POSITRON ANNIHILATION

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Abstract

We summarize the effects of some unknown supersymmetry breaking mechanism by the addition to the super-QCD Lagrangian of explicit, and different, mass terms for the scalar super-partners of quarks and antiquarks. Allowing also a possible Majorana mass for the gluino, we then calculate cross-sections for $e^+e^- \rightarrow$ two gluinos, a process which may be observable if the gluino is sufficiently long-lived.

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Supersymmetry, if realized in Nature, demands the existence of a color-octet fermion (the "gluino") associated with the gluon and hence massless if supersymmetry is unbroken. Since the gluino can have Yukawa couplings only to colored scalars, in the broken case it still cannot acquire a mass through their vacuum expectation values. Hence even when the breaking scale is around the weak boson mass, as in many current models, the gluino is expected to remain fairly light; radiative effects in some models [1] give it a mass $m_\lambda \approx 5$ GeV. Furthermore, the gluino may have a lifetime as long as 10^{-10} sec, according to reference [1], and thus may be relatively easy to discern experimentally.

Various mechanisms have been studied for the production of gluinos in e^+e^- annihilation [2] as well as in pp and $p\bar{p}$ collisions [3]. In the former case the mechanisms studied in reference [2] use the coupling of a gluino pair to a gluon derived from the three-gluon vertex of ordinary QCD (Figure 1). While this mechanism may be important on a $q\bar{q}$ resonance, it is sharply suppressed in the continuum unless the gluino mass is low compared with the beam energy. Otherwise the four-body state has very little phase space.

We would like to point out that gluinos may be pair produced in e^+e^- annihilation without quark jets, and that the corresponding cross-section near threshold may well dominate the one for the process in Figure 1. In order for the amplitude for $e^+e^- \to \lambda\lambda$ not to vanish, however, parity must be violated. This may be seen as follows: Since the outgoing gluinos are identical fermions, their final state must in the cms be odd under interchange. Since it must also have J=1, we have only the possibility $\ell=1$, s=1, and so there is just one invariant amplitude describing the process. Gluinos, however, are massive Majorana fermions

having imaginary intrinsic parity, so that an $\ell=1$ final state has $J^P = 1^+$. Since the original virtual photon was odd, parity must be violated.

In contrast to ordinary QCD, however, in broken supersymmetric QCD parity violation is to be expected. It arises through the masses of the quark and antiquark scalars[f1], m_A and m_B respectively, which in the broken case will not equal the quark masses and need not be equal to each other. After all, while we do not include the parity-violating electro-weak interactions explicitly, they may well be related to the actual mechanism of supersymmetry breaking. When we put in the breaking by hand, we may therefore take m_A and m_B to be unrelated constants, around the scale of the weak mass but probably at least 30 GeV by cosmological constraints [4]. Then gluino production can take place via the mechanisms in Figure 2; as expected, the graphs cancel in pairs in the limit $m_A \to m_B$.[f2] In Figure 2 the fermion lines represent two-component left-handed Weyl spinors, so that the arrows denote chirality. Note that these graphs, like those of Figure 1, give a cross-section proportional to $(\alpha\alpha_s)^2$; due to the simple two-body kinematics the appropriate value of α_s is unambiguous and may be taken [5] as 0.17.

Before calculating the one invariant amplitude, we can say a few things about it on general grounds. Since it describes a p-wave state we expect it to contain a factor of the velocity $\beta \equiv p/E$ (cms quantities) not found in the corresponding $e^+e^- \to \mu^+\mu^-$ case. When we attempt to build a candidate electromagnetic current operator out of gluino fields for incorporation into an effective Lagrangian, we find as expected that there is just one way to do so. Furthermore, in contrast to the case of Dirac fermions such an operator must contain the factor $k^\mu k^\nu - g^{\mu\nu}k^2$, where k is the virtual photon momentum, if the current is to be conserved.

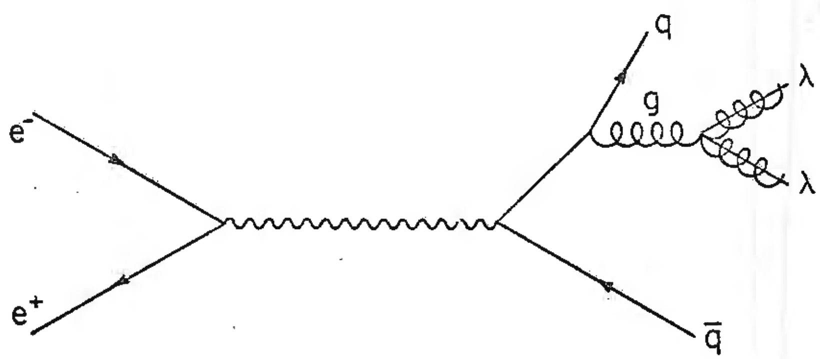

Figure 1

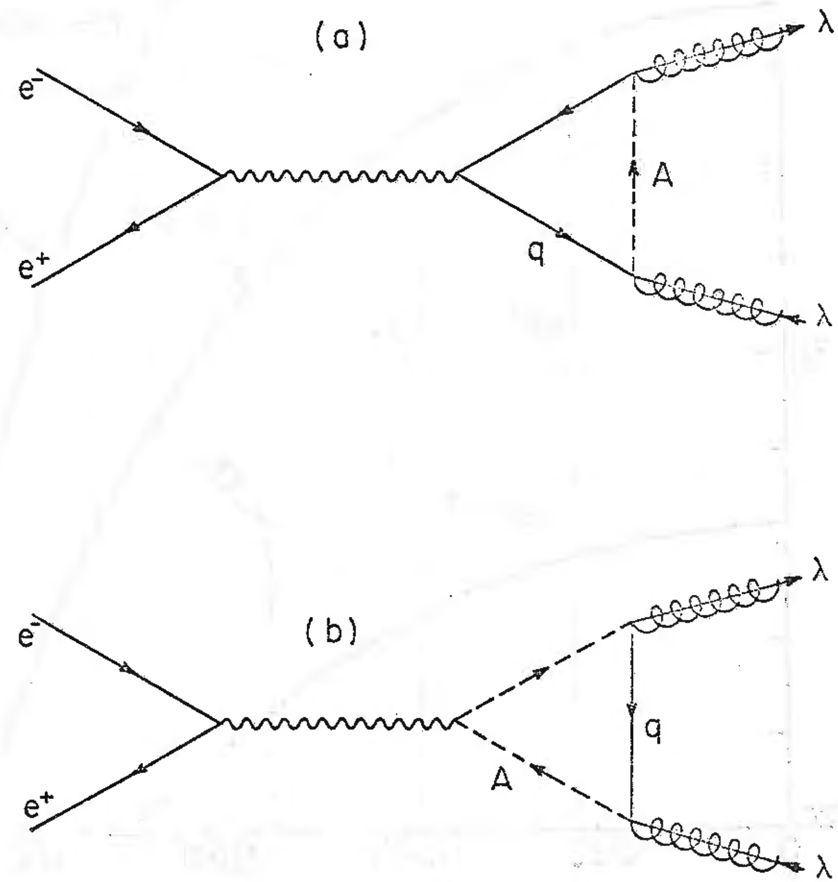

Figure 2

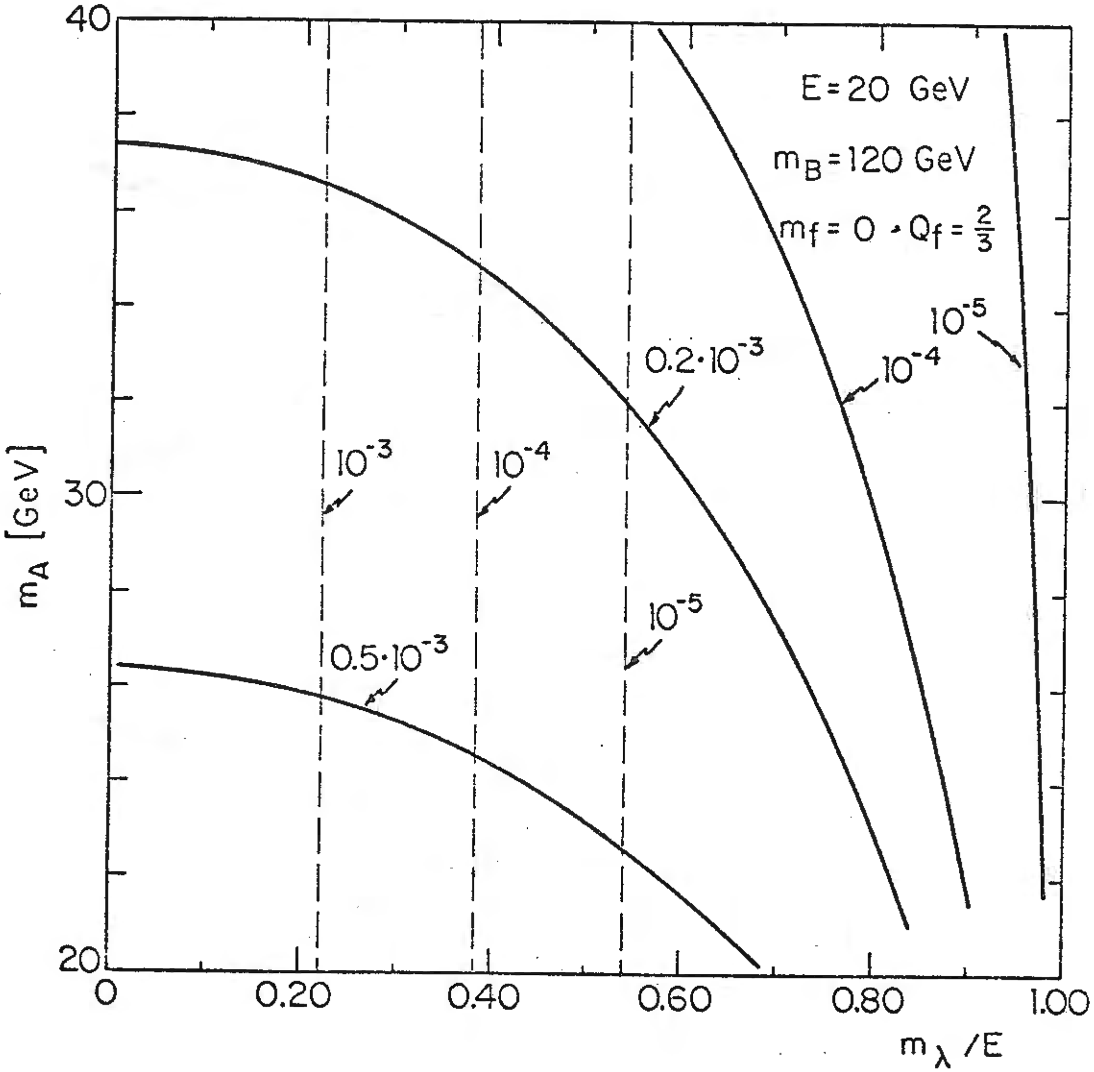
E=20 GeV
m_B=120 GeV
m_f = 0 , $Q_f = \frac{2}{3}$
10^{-5}
10^{-4}
$0.2 \cdot 10^{-3}$
10^{-3}
10^{-4}
10^{-5}
$0.5 \cdot 10^{-3}$
m_A [GeV]
40
30
20
0
0.20
0.40
0.60
0.80
1.00
m_λ /E

Figure 3

Thus we expect the amplitude to contain an extra factor of $s \equiv k^2$ compared to the Dirac case. This is also in keeping with the fact that the gluino's renormalized charge must vanish since its bare charge does, i.e. the electromagnetic form factor must vanish as $s \to 0$.

The unpolarized cross-section is (θ is the cms scattering angle):

$$\frac{d\sigma}{d\Omega} = \frac{(\alpha\,\alpha_s)^2\,\beta^3}{8\pi^2 s}\,(1+\cos^2\theta)\,\Big|\sum_f Q_f F_f\Big|^2, \qquad (1)$$

where the quark charge is eQ_f, the sum runs over quark flavors, and F_f is the form factor to be computed. This exhibits the expected factors of β. We note that the angular distribution is independent of the gluino mass. (Also, in the case of transverse incident beam polarization, the angular distribution is the same as for massless fermions.)

If we decompose the form factor as

$$F_f \equiv F_{f,A} - F_{f,B}, \qquad (2)$$

the Feynman rules give

$$F_{f,A} = \int_0^1 dx \int_0^{1-x} dy \left\{ \ln \frac{\xi(s,m_A^2,m_f^2,m_\lambda^2)}{\xi(s,m_f^2,m_A^2,m_\lambda^2)} - \xi^{-1}(s,m_A^2,m_f^2,m_\lambda^2)\,[xys - m_f^2 - (1-x-y)^2 m_\lambda^2] \right\}, \qquad (3)$$

and similarly $F_{f,B}$, where

$$\xi(s,M^2,m^2,m_\lambda^2) = (x+y)(1-x-y)m_\lambda^2 + xys + (x+y)(M^2-m^2) - M^2 + i\epsilon. \qquad (4)$$

In Eq. (3) m_f and m_λ denote quark and gluino mass, respectively. In the limit $m_\lambda = m_f = 0$, $s \ll m_A^2, m_B^2$, the form factor, Eq. (3), reduces to

$$F_{f,A} \simeq \frac{s}{m_A^2}\left[\frac{i\pi}{3} - \frac{1}{3}\ln\frac{s}{m_A^2} + \frac{1}{18}\right] + \left[\text{terms independent of } m_A^2\right]. \qquad (5)$$

As anticipated, in this limit F is proportional to s. As a result, the cross-section rises sharply as a function of s until s becomes larger than the lighter of the two scalar masses, whereupon it levels off. At these energies, however, the approximation used here of neglecting Z^0 exchange probably breaks down.

The results of a numerical calculation of the total cross-section for a single flavor of quarks are shown in Figure 3 at cms beam energy 20 GeV, divided by the similar cross-section for muon pair production $\sigma_{\mu\mu} = (4\pi/3)(\alpha^2/s)$ for reference. The addition of other quark flavors should not alter the picture substantially, since the sum over three generations tends to offset the partial cancellation due to different electric charges in each one. Figure 3 also shows the corresponding results for the lowest-order process in Figure 1, which of course are independent of m_A. As expected, near threshold or with a charitable choice of parameters our process can dominate the one with quark jets.

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Footnotes

Footnote 1: There is also the possibility of A-B mixing. Since this must arise from an F term, it is expected to be less important than the effect discussed in the text. (S. Dimopoulos, private communication.)

Footnote 2: At sufficiently high energies, however, new graphs involving Z^0 exchange will become important. These graphs will not tend to cancel as $m_A \to m_B$.

References

[1] e.g., M. Dine, W. Fischler and M. Srednicki, Nucl. Phys. B189 (1981) 575.

[2] B. Campbell, J. Ellis and S. Rudaz, Nucl. Phys. B198 (1982) 1.

[3] G.L. Kane and J.P. Leveille, University of Michigan Preprint UM HE 81-68 (1981).

[4] G. Barbiellini, et al., DESY Preprint 79/67 (1979).

[5] P. Söding and G. Wolf, Ann. Rev. of Nucl. and Part. Science 31 (1981) 231.

Figure Captions

Figure 1: Production of gluinos (λ) accompanied by quark jets.

Figure 2: Production of gluinos only. There are similar diagrams in which the quarks (q) and their scalars (A) are replaced by antiquarks ($\bar{q}$) and their scalars (B), and diagrams in which there are mass insertions on the quark lines in (a).

Figure 3: Contour plot of gluino production cross-section compared to muon pair production. The dashed lines represent the process in Figure 1 and are taken from reference [2]. The solid curves represent the process described in this paper.