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SPECTRUM OF GLUINO BOUND STATES

M. Chanowitz and S. Sharpe

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SPECTRUM OF GLUINO BOUND STATES*

M. Chanowitz

Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

and

S. Sharpe

Lawrence Berkeley Laboratory and Department of Physics
University of California, Berkeley, California 94720

Abstract

Using the bag model to first order in α_s we find that if light gluinos exist they will appear as constituents of electrically charged bound states which are stable against strong interaction decay. We review the present experimental constraints and conclude that light, long-lived charged hadrons containing gluinos might exist with lifetimes between 2×10^{-8} and 10^{-14} sec.

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Introduction

Supersymmetry has proved more theoretically attractive than experimentally observable.[1] It is important to press the search for the predicted supersymmetric partners of the known particles. We consider here the gluino ($\tilde{g}$), partner of the gluon, which in many models is light enough to be substantially produced in present experiments and long enough lived that the particles (shadrons) containing gluinos might travel an observable distance before decaying. It is important to know if the shadrons stable against strong decay are charged and/or neutral, since the former are easier to search for experimentally. We have calculated the s-wave shadron spectrum in the M.I.T. bag model. We find that if $m_{\tilde{g}} > 1$ GeV. then there are always strong interaction stable charged shadrons.

In confronting this result with predictions of supersymmetric models, it is important to keep in mind that the gluino mass which enters our calculations may differ from the mass that appears in the Lagrangian. As discussed below the former may be substantially larger than the latter.

We first summarize our calculation and then discuss the results in light of the theoretical models and the already established experimental constraints.

Calculation of Shadron Masses

The lightest color singlet bound states of gluinos are composed of $\bar{q}q\tilde{g}$, $g\tilde{g}$, and $\tilde{g}\tilde{g}$, of which only the $\bar{q}q\tilde{g}$ states carry electric charge. We call the latter meiktinos (or, perhaps, shermaphrodites) since they are partners to the $\bar{q}qg$ states -- called meiktons[F1] or hermaphrodites -- recently discussed by us[2] and others.[3] The $g\tilde{g}$ states, which are partners to glueballs, are named glueballinos and the $\tilde{g}\tilde{g}$ states gluinoballs. Strong decays of meiktinos can only produce other meiktinos or glueballinos, so we need only compute the meiktino and glueballino spectrum to discover if there are charged stable shadrons.

The bag model naturally contains valence gluons so that bound states of gluinos with gluons and with quarks are on the same footing. No extra assumptions (such as a "constituent" gluon mass) are needed to compare $g\tilde{g}$ and $\tilde{g}q\bar{q}$. In a recent paper[2] (hereafter referred to as I) we presented a fit to order α_s of the mesons, baryons and the glueball candidates ι(1440) and θ(1700). The $O(\alpha_s)$ quark and gluon self energies determined in that fit are crucial for comparing the $\tilde{g}g$ and $\tilde{g}q\bar{q}$ masses.

The lightest meiktinos and glueballinos are constructed from J = 1/2 s-wave quark and gluino modes and from the $J^{PC} = 1^{+-}$ TE gluon mode. Meiktinos consist of a color octet $\bar{q}q$ pair with $J^{PC} = 0^{-+}$ or 1^{--} combined with the gluino (with negative C and P undefined) to give three nonets, $J^C = 1/2^-, 1/2^+, 3/2^+$. There are two s-wave glueballinos, $J^C = 1/2^+, 3/2^+$. We will identify meiktinos by the flavor structure of the $\bar{q}q$ pair, e.g., $\tilde{\pi}_{1/2}$ for the $J^C = 1/2^-$ isotriplet.

Calculations are as in I except as noted below. The energy of a state is

$$E = \frac{4}{3}\pi R^3 B + \frac{Z_0}{R} + \sum_{\text{Constituents}} \frac{E_{\text{Mode}}}{R} + \Delta E \tag{1}$$

where B is the bag constant and Z_0/R has contributions from the zero point energy and from disconnected $0(\alpha_s)$ vacuum graphs. They are determined from fits to the known particles. ΔE contains all other $0(\alpha_s)$ corrections which we compute in time-ordered perturbation theory, the relevant diagrams being shown in Fig. 1.[F2] In the notation of I the $0(\alpha_s)$ energy shifts are

$$\begin{aligned}\Delta E_{\bar{q}q\tilde{g}} = \frac{\alpha_s}{R}\Big\{ & \Big[3\langle \vec{S}_q \cdot \vec{S}_{\tilde{g}}\rangle L^{ssTE}(m_q R) L^{ssTE}(m_{\tilde{g}} R)\frac{1}{\omega_{TE}} \\ & -\frac{3}{2} C^{ss}(m_q R, m_{\tilde{g}} R)\Big] + q \to \bar{q} \\ & -\frac{1}{3}\langle \vec{S}_q \cdot \vec{S}_{\bar{q}}\rangle L^{ssTE}(m_q R) L^{ssTE}(m_{\bar{q}} R)\frac{1}{\omega_{TE}} \\ & +\frac{1}{6} C^{ss}(m_q R, m_{\bar{q}} R) \\ & +\frac{1}{2} K \delta_{I,0}\delta_{S,1}\Big(L^{ssTM}(m_q R)^2 \frac{2\omega_{TM}}{4 E_s^2 - \omega_{TM}^2} \\ & \qquad + C'^{ss}(m_q R)\Big) \\ & + 2C_q + C_{\tilde{g}}\Big\}\end{aligned} \tag{2a}$$

$$\Delta E_{g\tilde{g}} = \frac{\alpha_s}{R}\Big\{ 12\langle \vec{S}_g\cdot\vec{S}_{\tilde{g}}\rangle L^{TE^3} L^{ssTE}(m_{\tilde{g}}R)\frac{1}{\omega_{TE}} - 3C^{sTE}(m_{\tilde{g}}R)$$
$$+\frac{3}{4}\left(1+2\langle \vec{S}_g\cdot\vec{S}_{\tilde{g}}\rangle\right)\left(\frac{L^{ssTE^2}(m_{\tilde{g}}R)}{\omega_{TE}} - \frac{L^{spTE^2}(m_{\tilde{g}}R)}{E_{p\frac{1}{2}}+E_s-\omega_{TE}}\right) \tag{2b}$$
$$-\frac{3}{2}\left(1-\langle \vec{S}_g\cdot\vec{S}_{\tilde{g}}\rangle\right)\frac{L^{sp'TE^2}(m_{\tilde{g}}R)}{E_{p\frac{3}{2}}+E_s-\omega_{TE}} + C_{TE} + C_{\tilde{g}}\Big\}$$

L, C^{ss}, and C^{sTE} are vertex and Coulomb integrals given in I. E_s, ω_{TE}, and ω_{TM} are mode energies in units of the inverse bag radius R^{-1}. The factor $\delta_{I,0}\delta_{S,1}$ K selects the isoscalar $\bar{q}q$ spin-triplet meiktinos, where K is a constant which is 2 for $\tilde{\omega}$ and 1 for $\tilde{\phi}$. C_q, $C_{\tilde{g}}$ and C_{TE} are the mode self energies in a spherical cavity, which are finite for massless quarks, gluinos and gluons and which for massive quarks and gluinos can be chosen by an appropriate mass renormalization to have the same value as in the massless case.[2] C_q and C_{TE} are determined by fitting to the known mesons and baryons and the glueball candidate θ(1700). $C_{\tilde{g}}$ differs from C_q only by the color factor $C_{\tilde{g}} = 9/4\ C_q$.

The energy of a state is then E_{MIN}, given by minimizing Eq. (1) with respect to R. But this state is a localized wave packet so its mass is $M^2 = E_{MIN}{}^2 - \langle P^2\rangle_{shadron}$. Here we follow Ref. (4) and approximate $\langle P^2\rangle_{shadron} = \sum P_{constituents}{}^2 = \sum ((E_{MODE}/R)^2 - M^2)_{constituent}$. In I we used a different prescription,[5] valid for masses of order 1 GeV. but not for the larger range considered here, in which the energy of localization was represented by a negative contribution to Z_0. A fit to the masses of ρ, p, Δ, ϕ, and Ω yields $B = (.144\ \text{GeV.})^4$, $Z_0 = -.9$, $m_u = m_d = 0$, $m_s = .30$ GeV., $\alpha_s = 1.8$, and $C_q = .2$. This is very similar to fit I of I except that Z_0 increases as expected in going from the prescription of Ref. (5) to that of Ref. (4). As explained below this fit is conservative in that other fits with larger α_s (analogous to fit II of I) increase the stability of the charged meiktinos.

As $m_{\tilde{g}}$ increases the gluino exerts smaller outward pressure on the bag and the radius decreases. To see whether it is necessary to allow α_s to vary with R and to test the model for states with heavy and light constituents we have calculated the masses of the charmed mesons and baryons. The calculations are as in Section III of I except that we use the center of mass prescription discussed above. We find a reasonable fit if α_s varies with R as shown in Table 1.[F3] It is gratifying that the sign of the variation is as expected from asymptotic freedom.

The fit suggests that we will be able to calculate shadron masses to a conservatively estimated uncertainty of ~50 MeV., but our conclusion that there are stable charged shadrons is stronger than this number suggests. In calculating the shadron masses we allow α_s to vary with R, interpolating the values of Table 1 for $3.6 < R < 5.0$ GeV.$^{-1}$ and using $\alpha_s = 1.8$ for $R \geq 5.1$ GeV.$^{-1}$ as determined in the fit to ρ, p, Δ, ϕ and Ω. Allowing α_s to run in this way is a conservative procedure since it turns out that decreasing α_s decreases the lightest $\tilde{g}g$ mass relative to the lightest $\bar{q}q\tilde{g}$ mass.

To fix C_{TE}, the gluon self energy, we fit as in I to the mass of the natural J^P glueball candidate $\theta(1700)$.[6] If $J^{PC}(\theta) = 2^{++}$ (suggested but not yet established by the data) then $C_{TE} = 1.00$ while if $J^{PC}(\theta) = 0^{++}$ then $C_{TE} = 2.36$. The absence in radiative ψ decay of any natural spin-parity glueball candidate below 1.70 GeV. implies $C_{TE} \geq 1.00$ which in turn bounds the $\tilde{g}g$ masses from below.

With these parameters we evaluate the shadron masses numerically as a function of $m_{\tilde{g}}$.[F4] The masses of the lightest relevant states, $\tilde{\rho}_{1/2}$, $\tilde{K}_{1/2}{}^*$, $\tilde{\pi}$ and $\tilde{g}g_{1/2}$, are shown in Table 2. The possible strong decays of the charged meiktinos are $\tilde{\rho}_{1/2} \rightarrow \tilde{g}g_{1/2} + \pi$; $\tilde{K}_{1/2}{}^* \rightarrow \tilde{g}g_{1/2} + K$; and $\tilde{\pi} \rightarrow \tilde{g}g_{1/2} + 2\pi$. We see from Table 2 that for $C_{TE} = 2.36$ there are always stable charged meiktinos with a margin of error which is already 600 MeV. at $m_{\tilde{g}} = 500$ MeV. and is even larger for larger values of $m_{\tilde{g}}$. In the worst case, $C_{TE} = 1.00$, the $\tilde{K}_{1/2}{}^*$ is stable with a margin of 75 MeV. for $m_{\tilde{g}} = 500$ MeV. which increases rapidly to a margin of 300 – 400 MeV. as $m_{\tilde{g}}$ increases.[F5] For $m_{\tilde{g}} > 1.5$ GeV. the $\tilde{\rho}_{1/2}$ is also stable by a comfortable margin > 100 MeV.

Discussion

We now discuss these results in the context of the current theoretical models and experimental constraints. The relevant parameters in addition to $m_{\tilde{g}}$ are the supersymmetry breaking scale Λ_s ($\langle H \rangle_0 = \Lambda_s{}^4$) and the squark mass $m_{\tilde{q}}$. The leading mechanisms for gluino decay are (A) $\tilde{g} \rightarrow \bar{q}q\tilde{\gamma}$ and

(B) $\tilde{g} \to g\tilde{G}$, where $\tilde{\gamma}$ is the photino and $\tilde{G}$ the Goldstino. These reactions give rise to gluino lifetimes of respectively[7]

$$\tau_A \cong 10^{-11} \left(\frac{m_{\tilde{q}}}{M_W} \right)^4 \left(\frac{1}{m_{\tilde{g}}\,(\mathrm{GeV.})} \right)^5 \mathrm{sec.} \tag{4a}$$

$$\tau_B \cong \left(\frac{\Lambda_s}{10\, m_{\tilde{q}}} \right)^4 \tau_A \tag{4b}$$

with M_W the W boson mass. Equations (4) assume $m_{\tilde{\gamma}}, m_{\tilde{G}} \ll m_{\tilde{g}}$, valid for all known globally supersymmetric models with light gluinos of nonzero mass, say $0 < m_{\tilde{g}} \lesssim 10$ GeV.

Such models fall into three categories. In type 1 models[8] supersymmetry and the electroweak gauge group are both broken in tree approximation, so that $\Lambda_s \lesssim 1$ TeV., $m_{\tilde{q}} \sim 0(M_W)$, and $m_{\tilde{g}} = 0$ if there is an R symmetry or $m_{\tilde{g}} \sim 0$ (few GeV.) from quantum corrections if the R-symmetry is broken. For type 2 models[9] $\Lambda_s \gtrsim 100$ TeV. arises from spontaneous symmetry breaking in a new ultra-heavy sector, and electroweak breaking occurs by radiative corrections with $m_{\tilde{q}} \sim 100$ GeV. – 1 TeV. If the R symmetry is broken $m_{\tilde{g}}$ also arises by quantum effects and because of cancellations is very light, perhaps as light as 0(1 GeV.).[10] In type 3 models[11] supersymmetry is broken dynamically by a supercolor sector, $\Lambda_s \cong 10$ TeV., which also breaks the R symmetry giving $m_{\tilde{g}} \sim 0(5$ GeV.) in three loops while $m_{\tilde{q}} \gtrsim 0(100$ GeV.) arises in two loops. In all these models $m_{\tilde{g}}$ is somewhat flexible. We use them as motivation for discussing a gluino with mass $m_{\tilde{g}} \lesssim 10$ GeV.

We can now estimate $\tau_{\tilde{g}}$ from Eq. (4). For type 1 models $\tau_A \sim 0(10^{-11} - 10^{-16}$ sec.) for $m_{\tilde{g}} \sim 1 - 10$ GeV. and $\tau_{\tilde{g}} \sim 0(\tau_B) \sim 0[(\Lambda_s/10\, m_{\tilde{q}})^4\, \tau_A]$ since $\Lambda_s \lesssim 10\, m_{\tilde{q}}$, thus we could have $\tau_{\tilde{g}} \sim 0(10^{-11} - 10^{-18}$ sec.). For type 2 and 3 models $\tau_{\tilde{g}} \sim 0(\tau_A) \sim 0(10^{-7} - 10^{-16}$ sec.). It is clear that the lifetimes are exceedingly sensitive to the precise values of the parameters. In all three types of models we could have $\tau_{\tilde{g}} > 10^{-14}$ sec. so that strong-interaction-stable meiktinos could travel an observable distance before decaying.

It is important to keep in mind however that the values of $m_{\tilde{g}}$ predicted in the models may differ from the value of $m_{\tilde{g}}$ appropriate to Eq. (4) which we identify with the input $m_{\tilde{g}}$ values used in our bag model calculations, since the latter masses may contain an extra nonperturbative component due to a $\tilde{g}\tilde{g}$ chiral condensate. Lattice methods indicate for color SU(2) that the chiral condensate for the adjoint representation occurs at much smaller distances than for the fundamental representation.[12] Assuming a similar result for color SU(3), a gluino inside the shadron bag would sense the $\tilde{g}\tilde{g}$ condensate. This contrasts with the usual situation of the quarks for which chiral and confining scales are about equal[12] so that current quark masses should be used in the bag interior (as is indeed required in bag phenomenology[2,13]). We know of no reliable method to estimate the nonperturbative component of $m_{\tilde{g}}$ except perhaps by computing shadron masses on the lattice. It may be large in which case the experimental lower limits on the "constituent" gluino mass based on Eq. (4) and the shadron spectrum would imply much weaker constraints on the "current" gluino masses derived from the models.

Lowest order perturbation theory[7] suggests hadroproduction of gluino pairs at 5 – 10 times the rate of quarks of the same mass,[F6] with $\sigma \propto m_{\tilde{g}}^{-(5-6)}$. They are also produced with lower rates in other processes such as e^+e^- annihilation.[14] They decay to photinos or Goldstinos which in the relevant models have weak or semi-weak interaction cross sections and live long enough to escape the detector.[15] The decay of a strong-interaction-stable shadron is then like the semileptonic decay of a heavy flavor but without the accompanying lepton.

The $\tilde{K}_{1/2}^*$ meiktino is a special case since if $\tau_{\tilde{g}}$ is large enough $\tilde{K}_{1/2}^*$ will decay by $\Delta S = 1$ weak interactions to $\tilde{g}g_{1/2}$, $\tilde{\rho}_{1/2}$, or $\tilde{\omega}_{1/2}$. This is most interesting if $m_{\tilde{g}} < 1.0$ GeV. since Table 2 shows that $\tilde{K}_{1/2}^*$ could then be the only strong interaction stable charged shadron. For $C_{TE} = 1.00$ and $m_{\tilde{g}} =$ 0.5 or 1.0 GeV. the $\tilde{K}_{1/2}^*$ may decay nonleptonically to $\tilde{g}g_{1/2} + \pi$, while for larger C_{TE} or $m_{\tilde{g}}$ the semileptonic decay to $\tilde{\rho}_{1/2} + e\nu$ might dominate. In either case we expect $\tau \gtrsim 0(10^{-10}$ sec.), the lifetime for hyperon decays, since $\tilde{K}_{1/2}^*$ and hyperon decays involve similar Q values and are both Cabibbo suppressed. The $\tilde{K}_{1/2}^*$ lifetimes could be longer because some of its decays require strong interaction corrections (e.g., gluon emission for $\tilde{K}_{1/2}^* \rightarrow \tilde{g}g_{1/2} + \pi$) which might suppress them relative to the hyperon decays. The nonleptonic $\tilde{K}_{1/2}^{*}$ decays would have the same signature as gluino decay, while the semileptonic decays would differ from charm decays by having zero strangeness, a much softer electron spectrum, and missing energy from both the ν_e and the subsequent $\tilde{g}$ decay.

Present experimental limits come principally from two sources. Beam contamination searches rule out very long-lived light shadrons:[1] assuming $\sigma_{prod} = (2\ \mathrm{GeV.}/m_{\tilde{g}})^5 \times 20\ \mu\mathrm{b.}$ and a conservative gluino-nucleon cross section of 1 mb., two FNAL experiments[16] require $\tau_{\tilde{g}} < 2-5 \times 10^{-8}$ sec. for $m_{\tilde{g}} \lesssim 10$ GeV. Equation (4) shows that this limit on $\tau_{\tilde{g}}$ is only a significant constraint for type (2) and (3) models with $m_{\tilde{g}} = 1$ GeV.[F7]

Since the photino/Goldstino scatter weakly as in neutral current ν scattering, beam dump experiments which measure the NC/CC ratio are also relevant. These give, for each gluino mass, lower limits on the mass of the lightest squark or on Λ_s depending, respectively, on whether the gluino decays to a photino or a goldstino. Using Eq. (4)[F8] these limits can be converted into lower limits on the gluino lifetime. For example if $m_{\tilde{g}} = 3.7$ GeV. and the gluino decays to a photino, then from Ref. (17) $m_{\tilde{q}} > 20$ GeV., $\tau_{\tilde{g}} > 4 \times 10^{-17}$ sec. and from Ref. (18) $m_{\tilde{q}} > 90$ GeV., $\tau_{\tilde{g}} > 10^{-14}$ sec. For Goldstino decay Ref. (18) found, for $m_{\tilde{g}} = 3$ GeV., that $\Lambda_s > .69$ TeV., $\tau_{\tilde{g}} > 10^{-14}$ sec. As $m_{\tilde{g}}$ decreases, the lower limits on $m_{\tilde{q}}$, Λ_s and on the gluino lifetime increase, and for $m_{\tilde{g}} \lesssim 1-2$ GeV. these limits are replaced by the condition that the gluino not rescatter in the beam dump before decaying. For instance, with $m_{\tilde{g}} = 1$ GeV. and $\tilde{g} \to \bar{q}q\tilde{\gamma}$, $E_{\tilde{g}} \cong 3E_{\tilde{\gamma}} = 3\,E_{vis} \gtrsim 60$ GeV. (using $E_{vis} \gtrsim 20$ GeV. as in both Refs. (17) and (18)), the requirement that the gluino decay within the 15 cm. interaction length of the Cu target implies $\tau_{\tilde{g}} < 10^{-11}$ sec. That is, for $\tau_{\tilde{g}} > 10^{-11}$ sec. the gluino rescatters in the dump losing energy so that the subsequent $\tilde{\gamma}/\tilde{G}$ cannot be detected. This dominates over the 10^{-10} sec. lower limit, derived from the limit on $m_{\tilde{q}}$, shown in Fig. (1) of Ref. (17). These limits severely constrain type 1 models: only $m_{\tilde{g}} > 3$ GeV. is allowed which implies $\tau_{\tilde{g}} \lesssim 10^{-14}$ sec. For types 2 and 3 models, however, no $m_{\tilde{g}}$ is excluded, although the shortest lived gluinos (i.e. the smallest Λ_s) are ruled out for $m_{\tilde{g}} \leqslant 4$ GeV. Thus beam dump experiments do not exclude the interesting cases of gluinos with masses $\leqslant 10$ GeV. which live long enough to leave observable tracks.

There is another interesting possibility which must be kept in mind in interpreting the beam dump experiments. In models in which the selectron is sufficiently lighter than the lightest squark, $(m_e/m_q) < (\alpha\ m_{electron}/\alpha_s <x> m_{proton})^{1/4} = 0.1$, the photino scatters predominately from the electrons in the target and the NC/CC anomaly is determined by m_e.

It is clear from this brief survey that gluinos with masses less than 10 GeV. could easily have escaped detection. The most interesting possibility is of very light gluinos, $m_g \sim 0(1\ \text{GeV.})$ with 10^{-11} sec. $< \tau < 2.10^{-8}$ sec., too short lived for beam contamination experiments and too long lived for beam dump experiments. For larger gluino masses the experimental constraints on τ_g become even weaker and in particular the interesting range from $10^{-11} - 10^{-14}$ sec. is possible. We have shown for all $m_g > 1$ GeV. that there will be charged shadrons stable against strong interactions or decaying weakly with a long lifetime. Light gluinos might be the only signal of supersymmetry accessible to present experiments so it is important to extend the search to cover these possibilities.

Acknowledgments

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Footnotes

F1 Meikton from the Greek for a mixed thing -- we thank the classicist M. Whitlock-Blundell for suggesting this term.

F2 Contributions from intermediate radial excitations and d-wave quarks are very small and are not shown. We also ignore squark intermediates which are negligible since squarks are very heavy ($\gtrsim 0(M_W)$) in the models we consider.

F3 We do not include $d\alpha_s/dR$ when minimizing E, since we only know $\alpha_s(R)$ roughly and the error introduced is of order 50 MeV., the same order as other uncertainties.

F4 For $m_{\tilde{g}} = 0$ and $m_{\tilde{g}} \to \infty$ we checked the results analytically.

F5 The margin of error is also indicated by the following: for $m_{\tilde{g}} = 2$ GeV. if we decrease C_{TE} to the point that $\tilde{g}g_{1/2}$ is 500 MeV. lighter than $\tilde{K}_{1/2}{}^*$, just enough to allow $\tilde{K}_{1/2}{}^*$ to decay strongly, the mass of the $J^{PC} = 2^{++}$ glueball drops to 1.0 GeV.

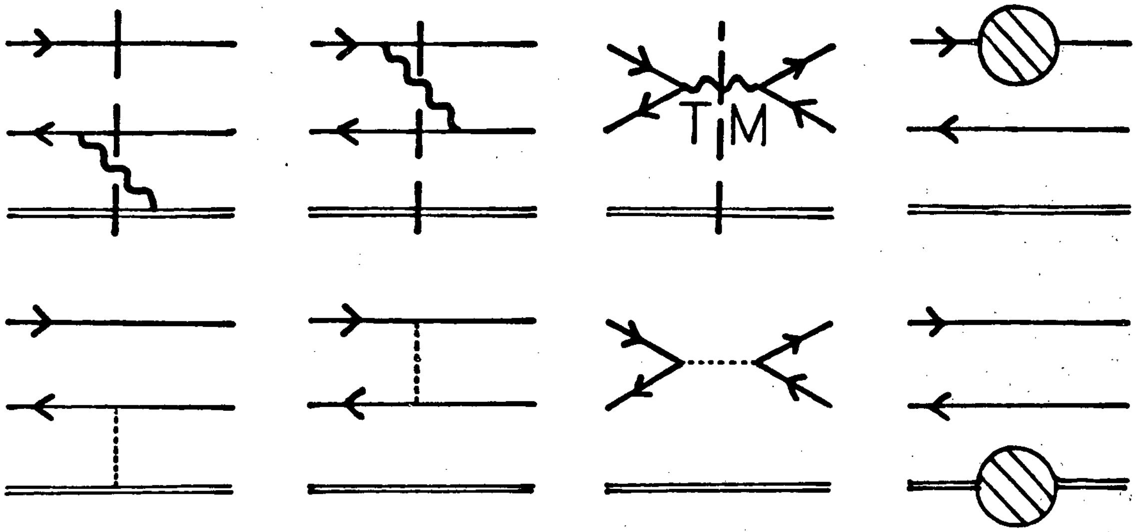
F6 Perturbation theory calculations may have to be corrected because of the $\tilde{g}\tilde{g}$ condensate discussed above, e.g., for a very hard process with a distance scale smaller than the chiral symmetry restoration scale one should use the current $m_{\tilde{g}}$ in the Feynman amplitude.

F7 Our conclusion is weaker than the analogous limit of Ref. (7) which was based on Gustafson *et al.*, the second of our Refs. (16). The difference is that the authors of Ref (7) assumed a several meter free-flight path length which is two orders of magnitude smaller than the actual length. We thank I. Hinchliffe for a discussion.

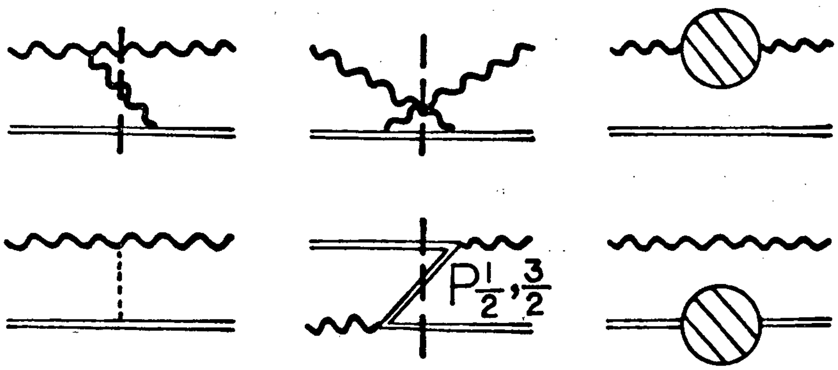
F8 We assume, as is likely in global supersymmetry, that the same $m_{\tilde{q}}$ controls $\tau_{\tilde{g}}$ and $\tilde{\gamma}$ scattering in the case when the gluino decays into a photino.

Figure Caption

Figure 1: Diagrams giving order α_s energy shifts for (a) Meiktinos and (b) Glueballinos. Only one time ordering is shown, and diagrams with quark and antiquark interchanged are not shown. The double line represents a gluino, the dotted line a coulomb interaction, and the dashed line the intermediate state. The blob represents the $0(\alpha_s)$ self energy. Unless otherwise indicated the fermions are in $S_{1/2}$ modes and the gluons are in TE modes.



(a)



(b)

Figure 1

Table I. Charmed hadron masses in the bag model. These results are for $m_c = 1.65$ GeV. Masses are in GeV. and radii in GeV.$^{-1}$.

Particle	D	D*	F	F*	Λ_c
M_{expt}	1.87	2.01	2.02	2.14	2.28
M_{bag}	1.87	2.02	2.00	2.13	2.30
R_{bag}	4.1	4.5	4.0	4.4	5.0
α_s	1.4	1.5	1.4	1.5	1.7

Table II. Shadron masses for various gluino masses. Bag parameters are B = 4.28 10^{-3}(GeV.)^4, $Z_0 = -0.9$, $m_u = m_d = 0$, $m_s = 0.3$ GeV., $C_q = 0.2$, $C_{TE} = 1.00$ and 2.36 and $\alpha_s(R)$ is extrapolated from Table I.

$M_{\tilde{g}}$	$\tilde{g}g_{1/2}$ ($C_{TE} = 1.00$)	$\tilde{g}g_{1/2}$ ($C_{TE} = 2.36$)	$\tilde{\rho}_{1/2}$	$\tilde{K}_{1/2}{}^*$	$\tilde{\pi}$
0.5	.80	1.45	1.02	1.22	1.36
1.0	1.45	2.04	1.54	1.71	1.78
1.5	2.02	2.59	2.06	2.24	2.24
2.0	2.56	3.12	2.60	2.75	2.73
2.5	3.09	3.64	3.12	3.26	3.23
3.0	3.61	4.15	3.63	3.77	3.73
3.5	4.13	4.66	4.14	4.27	4.23
4.0	4.64	5.17	4.64	4.78	4.73
4.5	5.15	5.67	5.15	5.28	5.23
5.0	5.66	6.18	5.66	5.79	5.73
7.5	8.18	8.70	8.17	8.30	8.23
10.0	10.70	11.21	10.68	10.81	10.74
15.0	15.71	16.22	15.69	15.82	15.74
20.0	20.72	21.23	20.70	20.83	20.74

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720