POSSIBLE IMPLICATIONS OF A LIGHT GLUINO

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Abstract

Light gluinos have been suggested in order to reconcile $\alpha_s$ determinations from low energy deep inelastic experiments with those inferred from LEP measurements. From this hypothesis then one expects, in unified N=1 supergravity models, that also the "photino" will be light. We show that this possibility is not in conflict with recent LEP measurements and also that cosmology does not necessarily rule it out in any convincing way. Moreover it leads to upper limits on the masses of the other supersymmetric fermions, for example, the lightest chargino should be lighter than about 75 GeV
There is a lot of controversy on whether or not the existence of light gluinos, of mass $2\lesssim m_{\tilde{g}} \lesssim 6$ GeV, has been confidently ruled out [1, 2, 3]. While this possibility is theoretically marginal and there is much circumstantial evidence against it, we have been recently encouraged by the fact that light gluinos might account for the apparent discrepancy between the values of the strong coupling constant $\alpha_s$ as determined from low energy deep inelastic experiments and those inferred from high energy LEP experiments. Indeed, the results of deep inelastic lepton-nucleon scattering give $\alpha_s(M_Z) = 0.112 \pm 0.004$ at the Z mass scale, which is lower than the results of $e^+e^-$ analyses of event shapes. The averaged LEP value obtained this way is $\alpha_s(M_Z) = 0.124 \pm 0.005$ [4].

While it is perfectly possible that the theoretical uncertainties are underestimated in the above analyses [5] one can also envisage an alternative solution which should not be overlooked unless one can convincingly exclude it from experiment, namely, the existence of an electrically neutral coloured fermion of relatively low mass. This would slow down the running of $\alpha_s$ between the scales accessible at LEP and those being probed by deep inelastic experiments. Indeed, the evolution of $\alpha_s$ between 5 and 90 GeV is described much better if we postulate a light gluino than if we do not [6]. Similar arguments were also given in ref. [7] on the basis of quarkonia data.

If gluinos are light one also expects the ”photino” to be light. This is the case in the most popular class of N=1 supergravity models where there is a common supersymmetry breaking mass parameter at the unification scale [8]. In these theories most likely the lightest of the neutralinos is the lightest supersymmetric particle (LSP) and is mostly a ”photino”. The masses and mixing angles of the charged and neutral supersymmetric fermions, charginos and neutralinos, are then determined by only three independent parameters: the gluino mass, which we may fix anywhere in the range of interest, the ratio of the two Higgs vacuum expectation values $\tan \beta = \frac{v_u}{v_d}$, and the Higgsino mixing parameter $\mu$.

In this note we show that the possibility of light gluinos in the context of supergravity models is not in conflict with the recent measurements of the Z decay widths, sensitive to the possible presence of supersymmetric Z decay channels, as well as the direct supersymmetry searches at LEP. The relevant constraints may be summarized as [1, 9]

1. The limit on mass of the lightest of the charginos $m_{\tilde{\chi}^\pm} \geq 45$ GeV
2. The LEP limits on the total $Z$ width, $\Gamma_{Z}^{total} = 2.487 \pm 0.010$ GeV,
3. The LEP limit on the invisible $Z$ decay width, $\Gamma_{\text{inv}} = 498 \pm 8$ MeV

In addition to these we have also included the LEP limit on the hadronic peak cross section as well as the limits from $p\bar{p}$ colliders on the ratio of $W$-to-$Z$ cross sections $0.825 \leq \frac{R}{R_{SM}} \leq 1.091$, which could also be modified by the existence of supersymmetric decay channels.

For fixed gluino mass one can determine the region of supersymmetric parameters allowed by the LEP experiments just in terms of $\mu$ and $\tan \beta$. We have determined what this region is for arbitrary values of the gluino mass in the range $m_{\tilde{g}} \leq 7$ GeV. The result is shown in figure 1. We see that there is a finite, but nonnegligible butterfly-shaped region of allowed $\mu$ and $\tan \beta$ values. In particular, this shows explicitly that a very light neutralino (most likely the LSP) is perfectly consistent with the LEP measurements of $\Gamma_Z^{\text{invisible}}$ if the supersymmetry breaking gaugino mass parameters are small. The reason for this is clear: in the limit of strictly vanishing soft-breaking gaugino masses the LSP is a pure photino, and it is massless, forming an unbroken supersymmetric multiplet with the photon. Such a state is decoupled from the $Z$, and therefore no limits can be set from LEP. How about cosmology?

If the LSP is a neutralino, almost pure photino, then the relic LSP density will be, to a very good approximation, inversely proportional to the LSP annihilation cross section which, in turn, is roughly proportional to $m_{\tilde{\gamma}}^2/m_{\tilde{\chi}_1^0}^4$. Requiring it not to be too large one obtains a lower bound on the LSP mass, for this case:

$$m_{\tilde{\gamma}} \gtrsim 1 \text{GeV} \times \left(\frac{m_{\tilde{\chi}_1^0}}{45 \text{GeV}}\right)^2$$  

which, from the LEP bound on selectrons, leads to $m_{\tilde{\gamma}} \gtrsim 1$ GeV. For such masses the annihilation of relic photinos is sufficient to dilute their number density to an acceptable level.

What if $m_{\tilde{\gamma}} \lesssim 1$ GeV? In this case one would have to rely on some photino decay mechanism in order to avoid a conflict with the standard cosmological picture. If R parity is conserved, the photino will be absolutely stable. Thus the simplest way out is to allow for a small amount of R parity violation. Such possibility is definitely allowed by experiment and there are several extensions of the minimal supersymmetric standard model where R parity violation can occurs [11, 12, 13].

If the photino is very light and decays with a substantial branching ratio to photons or charged particles, there may be strong astrophysical and cosmological

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3We have not applied the constraint $\tan \beta \geq 1$ that holds in models with radiative electroweak breaking.
restrictions on its lifetime and mass, following from nucleosynthesis considerations and the isotropy of the relic photon background. It is, however, certainly possible to obey these restrictions in realistic models with explicitly broken R parity. Moreover, these constraints can be completely avoided if the low-lass photino decays invisibly, as expected in the case of the simplest \( SU(2) \otimes U(1) \) models where R parity is broken just spontaneously \[12\]. In the latter case the photino decays mostly by majoron emission, \( \tilde{\chi}^0 \to \nu + \text{majoron} \), and no important constraints can be placed from cosmology. On the other hand, its laboratory missing energy signatures may be indistinguishable from those it has in the minimal supersymmetric standard model, to the extent that the invisible decay is dominant.

We conclude that cosmological arguments can not convincingly rule out the existence of a light photino.

We now note that in this class of supergravity models it is possible, although marginally, to induce small gluino and photino masses just as a result of radiative corrections \[14\]. Gluino masses around 2 GeV may arise this way, mostly from a top-stop loop. In this estimate the constraint on the value of \( \mu \) that follows from figure 1, \( \mu \lesssim 120 \text{ GeV} \), plays an important role. The required large values of \( m_{\text{top}} \) are, however, not the ones which are favored by precision data \[9, 15\]. For the case of the photino, whose mass also receives electroweak corrections \[14\], masses close to 1 GeV are possible, for acceptable values of \( m_{\text{top}} \) and \( \mu \). Higher values for gluino and photino masses would require the existence of a primordial nonzero supersymmetry breaking mass parameter at the unification scale.

An interesting point to mention is that the expected mass spectrum in our class of light-gluino supergravity models is characterized by relatively light supersymmetric fermions. This follows from the allowed region of \( \mu \) and \( \beta \) values shown in figure 1. Indeed, for such allowed parameter values it follows that the charginos and neutralinos should be accessible at future accelerators. For example, figure 2 shows the region of allowed chargino masses. Clearly, one sees that the lightest chargino should be lighter than about 75 GeV. A similar upper bound also applies to the next-to-lightest of the neutralinos. Moreover, if the relic photino population disappears only due to selectron-mediated annihilations, also selectrons would very close to the present limit, from eq. (1). A quick inspection at the renormalization group equations then shows that the other sfermions would also be light in this case. Although squarks are somewhat heavier, due to colour, they too should lie in the region of sensitivity of hadron collider experiments. One way to make the model "safer" from being experimentally disproved would be to allow for some R parity violation, so that the
photino can decay, as described above. This would relax the limits on the sfermions masses, allowing them to be heavier. However, the implied upper limits on the chargino and neutralino masses would still hold.

In conclusion we would like to stress that neither the existing data from LEP nor cosmological considerations preclude the possibility that a light photino exists, as would be expected in N=1 supergravity models where gluinos are sufficiently light as to play a significant role in the running of $\alpha_s$ between 5 and 90 GeV. The resolution of the controversy on whether or not the existence of light gluinos can be confidently ruled out must rest upon the results of hadron colliders and depend on the gluino lifetime and on the details of the strongly interacting supersymmetric spectrum. As suggested in [6], future searches for evidence of a light gluino in 4-jet $e^+e^-$ or 3-jet $e^+e^-$ events should be pursued by the experiments at LEP and HERA. Here we have stressed the important complementary role played by future searches for the other electroweakly interacting supersymmetric fermions. For example, we have showed that the lightest chargino should be lighter than about 75 GeV, with a similar upper limit applying also to the neutralino immediately heavier than the photino.

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Figure Captions

Fig 1:
Regions of allowed $\mu$ and $\tan \beta$ values in unified N=1 supergravity models with light gluinos.

Fig 2:
Region of allowed chargino masses in light-gluino supergravity models.
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