IMPLICATIONS OF A LIGHT GLUINO

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ABSTRACT

We show that the possibility of having light gluinos is not in conflict with recent LEP measurements and also that cosmology does not rule it out in any convincing way. In unified N=1 supergravity models, one expects that also the "photino" will be light. 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, an thus detectable at LEP200.

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]. Although this possibility is theoretically marginal, 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. The results of deep inelastic lepton-nucleon scattering give $\alpha_s = 0.112 \pm 0.005$ 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 $\alpha_s = 0.124 \pm 0.005$ [4]. 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 [5]. Similar arguments were also given in ref. [6] on the basis of quarkonia data.

The existence of an electrically neutral coloured fermion of relatively low mass could be envisaged as a possible solution which should not be overlooked unless one can convincingly exclude it from experiment. In supersymmetry the natural candidate is the supersymmetric partner of gluon, namely the gluinos, in the most popular class of N=1 supergravity models if gluinos are light one also expects the "photino" to be light. Considering a common supersymmetry breaking mass parameter at the unification scale [7], masses and mixing angles of the charged and neutral supersymmetric fermions, charginos and neutralinos, are 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 LEP data. The relevant constraints may be summarized as [8, 9]

1. The limit on mass of the lightest of the charginos $m_{\tilde{\chi}^\pm} \geq 45$ GeV

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2. The LEP limits on the total $Z$ width, $\Gamma_{\text{total}}^Z = 2.487 \pm 0.010$ 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 $0.825 \leq \frac{R}{R_{\text{SM}}} \leq 1.091$, 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 $m_{\tilde{g}} \approx \lesssim 7$ GeV. The result is shown in figure 1. We see that there is a finite, but noneglibible 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 $\Gamma_{\text{invisible}}^Z$ 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.

Now we move to cosmology. If the LSP is a neutralino, almost pure photino, then the relic LSP density will be, to a good approximation, inversely proportional to the LSP annihilation cross section which, in turn, is roughly proportional to $m_{\tilde{\gamma}}^2/m_{\tilde{\chi}}^4$. Requiring it not to be too large one obtains a lower bound on the LSP mass, for this case: $m_{\tilde{\gamma}} \gtrsim 1$ GeV $\times (\frac{m_{\tilde{\gamma}}}{45 \text{GeV}})^2$ 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. If $m_{\tilde{\gamma}} \lesssim 1$ GeV 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 occur. For example, in the case of spontaneous R-parity breaking the photino decays mostly by majoron emission, $\chi^0 \rightarrow \nu + \text{majoron}$, a decay mode basically unconstrained by astrophysics and cosmology. On the other hand, the laboratory missing energy signatures associated to the LSP 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 around 2 GeV, mostly from a top-stop loop.

A most striking consequence of the light gluino supergravity scenario 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 the charginos and neutralinos should be accessible at future accelerators like LEP200. For example, figure 2 shows the region of allowed chargino masses. Clearly, one sees that the lightest chargino

\footnote{We have not applied the constraint $\tan\beta \geq 1$ that holds in models with radiative electroweak breaking.}
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. (3). 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 [3], future searches for evidence of a light gluino in 4-jet $e^+e^-$ or 3-jet $ep$ events should be pursued by the experiments at LEP and HERA. Here we have stressed the important complementary role played by future searches at LEP200 for the 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. These particles should be accessible at LEP200.

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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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