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BOUNDS ON SUPERSYMMETRIC PARTICLES FROM A PROTON BEAM-DUMP EXPERIMENT

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A B S T R A C T

We estimate the magnitude of effects induced by gluino hadroproduction and subsequent gluino decay into a photino and hadrons in a proton beam - dump experiment. By comparing our estimates with results obtained by us in an experiment performed at the CERN SPS we set a lower bound on the gluino mass which is a function of the scalar quark mass. The results do not favour the existence of low mass gluinos (< 2 GeV) and scalar quarks (< 100 GeV).

Theoretical models with low-energy supersymmetry are widely discussed at present. These models predict supersymmetric partners of ordinary quarks, leptons, and bosons at a mass scale of 100 GeV which will become accessible at future generation accelerators. However, these models also predict particles with naturally small masses. These are the supersymmetric partners of gluons and photons - gluinos and photinos. In the limit of exact symmetry their masslessness is guaranteed not only by supersymmetry itself but also by the so-called R-invariance which is an analog of the well known chiral symmetry.

Phenomenological implications of gluinos and photinos have been first discussed by P.Fayet and G.Farrar [1]. Various mechanisms of R-symmetry breaking have been considered by one of us (M.I.V.) [2]. The conclusion is that a gluino mass of the order of a few GeV cannot be ruled out on purely theoretical grounds and moreover it is in some respect natural.

Limits on the gluino mass derived from existing data have been recently discussed in ref.[3]. The aim of the present paper is to make more detailed estimates for a gluino signal in beam-dump experiments and to compare them with results obtained by us in an experiment performed in 1979 [4] to study prompt neutrino production. (Preliminary results were reported previously [5].)

A chain of three processes leads to a signal in beam-dump experiments. They are :

- (i) hadroproduction of gluino pairs in proton-nucleus collisions;
- (ii) gluino decay into a photino and hadrons $\tilde{g} \rightarrow \tilde{\gamma} q \bar{q}$;
- (iii) photino-induced interaction in the beam-dump detector $\tilde{\gamma} q \rightarrow \tilde{g} q$ which is the cross-channel of process (ii).

The latter process resembles neutral-current neutrino interactions but with smaller missing energy. We will not, however, employ the difference in the y -distributions between photino-induced and neutrino-induced interactions, but will establish an upper limit on the production of muonless events in excess of those expected from neutrino interactions in a proton beam-dump experiment.

In each of the three processes there are factors which enhance gluino production with respect to that of heavy quarks of comparable mass.

Gluino hadroproduction via the gluon fusion mechanism is enhanced by the color factor of $81/7$ (see the Appendix) because gluinos belong to the adjoint representation of the color $SU(3)$ group.

Process (ii) is the only decay mode of the gluino, whereas heavy quarks have semileptonic branching ratios of order 10%.

The photino interaction cross-section is semi-strong, and thus it is large with respect to the neutrino weak interaction cross-section.

It should be noted that our analysis does not depend on details of supersymmetric models, but relies only on the fact that the photino mass can be neglected in comparison with that of the gluino. As a result, a lower bound on the gluino mass depends solely on one parameter, the scalar quark mass.

To get an upper limit on the product of the gluino production cross-section and the photino interaction cross-section, we have used results obtained by us in a proton beam dump experiment performed at the CERN SPS in 1979 [4].

In the exposure of 6.96×10^{17} protons on the full density target (a 2m long copper block), $80.5 \pm 14(\text{stat}) \pm 6.3(\text{syst})$ muonless events of prompt origin with $E_{\text{vis}} > 20$ GeV have been observed. These events include charged current (CC) and neutral current (NC) interactions of ν_e and $\bar{\nu}_e$ as well as interactions of neutrino-like particles without a muon in the final state. The number of prompt CC events induced by ν_e and $\bar{\nu}_e$ has been estimated to be $60.7 \pm 13(\text{stat}) \pm 5.3(\text{syst})$ by direct identification. From this number of CC events we calculated the corresponding number of NC events with $E_{\text{vis}} > 20$ GeV to be $15.8 \pm 3.4(\text{stat}) \pm 1.5(\text{syst})$. Subtracting these ν_e and $\bar{\nu}_e$ events from the observed number of muonless events we find 4 ± 21 events with $E_{\text{vis}} > 20$ GeV in a target of 100 tons fiducial weight within the solid angle of 6.8×10^{-6} sterad, subtended by the detector which could be attributed to the interaction of other neutrinos or neutrino-like particles.

Expected photino rates were calculated by Monte-Carlo simulation. Gluino production and decay and subsequent photino interactions were generated as described in the Appendix. A linear A dependence was assumed for gluino production. Results deduced from the observed excess rate as compared to these expected rates are plotted in Fig.1. The solid curve is a lower bound at 90 % c.l. The broken lines indicate the gluino lifetime constraints. One can see that for $m_{\tilde{g}} < 1.5$ GeV the allowed values of the scalar quark mass correspond to rather long-lived gluinos. In particular, gluinos with $m_{\tilde{g}} \approx 1$ GeV should have a lifetime ¹⁾ $> 10^{-10}$ sec and only a few percent of them would decay in the dump target.

Finally we would like to point out that the bound given should be considered as a conservative one at least at gluino mass values below 2 GeV, since the standard gluon fusion mechanism used to calculate production of $\tilde{g}\tilde{g}$ predicts smaller cross-sections than the observed ones in the case of $c\bar{c}$ [3,6]. Similar calculations performed at $m_{\tilde{g}} = m_D$ with an invariant gluino production cross-section of the form $(1 - |x|)^2 \exp(-2p_t)$ which fits $D\bar{D}$ production and which is normalized to the value $\sigma(pp \rightarrow D\bar{D} + X) = 15 \mu\text{b}$ (derived from our measurements [4] using $\text{BR}(D \rightarrow \nu_e e X) = 0.10$) multiplied by the color factor, gives a limit on M_S which is 2.1 times higher.

In conclusion, the results of our search for supersymmetric particles do not favour the existence of low mass gluinos (< 2 GeV) and scalar quarks (< 100 GeV).

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1)

This also means that the expected signal from long-lived gluinos would behave proportionally to the inverse target density.

APPENDIX

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Gluino hadroproduction.

To calculate the gluino production cross-section we use the QCD perturbation theory calculation via the gluon fusion mechanism pictured in Fig.2. The magnitude of the cross-section can be easily understood if we compare $\tilde{g}\tilde{g}$ production with $q\bar{q}$ production. For equal Q^2 $\tilde{g}\tilde{g}$ production is enhanced by the color factor

$$\frac{1}{2} \frac{\text{Tr}(F^a F^a F^b F^b + F^a F^b F^a F^b)}{\text{Tr}(\lambda^a \lambda^a \lambda^b \lambda^b + \lambda^a \lambda^b \lambda^a \lambda^b)/16} = \frac{81}{7}. \quad (A1)$$

Here F^a are the matrices made out of the SU(3) structure constants f^{abc} (generators in the adjoint representation), λ^a are the Gell-Mann SU(3) matrices and the overall factor of 1/2 is because gluinos are Majorana spinors.

The invariant matrix element squared (summed over the polarizations and color of the gluinos, and averaged over the polarizations and color of the initial gluons) has the form

$$|M|^2 = 1/2(6\pi\alpha_s)^2 \left\{ \frac{(p_1 k_1) + 2m^2}{(p_1 k_2)} + \frac{(p_1 k_2) + 2m^2}{(p_1 k_1)} - \frac{(p_1 k_1)^2 + (p_1 k_2)^2}{(k_1 k_2)^2} - \frac{m^4}{(p_1 k_2)^2} - \frac{m^4}{(p_1 k_1)^2} - \frac{m^4}{(p_1 k_1)(p_1 k_2)} - \frac{2m^2}{(k_1 k_2)} \right\}. \quad (A2)$$

Here α_s is the QCD coupling constant and we take it as

$$\alpha_s(Q^2) = \frac{12\pi}{25 \ln(Q^2/\Lambda^2)} \quad (A3)$$

with $\Lambda = 200$ MeV. m is the gluino mass. $k_1, k_2(p_1, p_2)$ are 4-momenta of the incoming gluons (outgoing gluinos).

The cross-section corresponding to the matrix element (A2) was convoluted with the internal gluon fluxes as determined by the gluon structure function. For the latter we use $G(x, Q^2)$ as obtained by CDHS group from the analysis of high-energy neutrino and antineutrino interactions [7].

Gluino decay.

Gluino decay into a photino and a $q\bar{q}$ pair is described by the diagram of Fig.3. The interaction is mediated by a scalar quark whose mass is of the order of the supersymmetry breaking mass scale ($O(100 \text{ GeV})$). For the gluino decay-rate into a photino and a massless quark-antiquark pair of given flavour having an electric charge Q_q we have, from Fig.3 :

$$\Gamma = Q_q^2 \frac{\alpha\alpha_s}{48\pi} \cdot \frac{m^5}{M_s^4} \quad (\text{A4})$$

where M_s is the scalar quark mass of the same flavour. Summing over u,d and s flavours we get the following estimate of the gluino lifetime

$$\tau = 1 \times 10^{-11} \left(\frac{1 \text{ GeV}}{m} \right)^5 \left(\frac{M_s}{100 \text{ GeV}} \right)^4 \text{ sec.} \quad (\text{A5})$$

The photino energy spectrum in gluino decay is given by

$$\frac{1}{\Gamma} \frac{d\Gamma}{d\eta} = 2 (3\eta^2 - 2\eta^3) \quad (\text{A6})$$

where η is related to $E_{\tilde{\gamma}}$, the photino energy in the gluino rest frame:

$$\eta = 2 E_{\tilde{\gamma}}/m.$$

Photino interactions.

The dominant mechanism for the photino-nucleon interaction is the inverse of gluino decay 2). For the cross-section the diagram of Fig.3 yields

$$\sigma = \frac{32 \pi \alpha \alpha_s}{9 M_s^4} s \int \sum Q_q^2 \left(1 - \frac{m^2}{xs}\right)^2 \left(1 + \frac{m^2}{8xs}\right) x q(x) dx \quad (\text{A7})$$

where the sum runs over all quark and antiquark distributions.

2)

The other possible mechanism is photino-quark scattering $\tilde{\gamma}q \rightarrow \tilde{\gamma}q$. Since this process is purely electromagnetic, its cross-section is smaller by two orders of magnitude than that for the inverse of gluino decay.

Figure captions.

Fig.1 The 90% c.l. lower bound on the gluino mass as a function of the scalar quark mass. The broken lines show the gluino lifetime constraints.

Fig.2 Diagrams for gluon fusion into a gluino pair.

Fig.3 Diagram for the interaction of a gluino and a photino with quarks.

References.

- [1] P.Fayet. Phys.Lett.78B,417(1978)
G.R.Farrar and P.Fayet. Phys.Lett.76B,575(1978);79B,442(1978)
- [2] M.I.Vysotsky. Preprint ITEP-43(1982), submitted to Nucl.Phys.B
- [3] G.L.Kane and J.P.Leveille. Phys.Lett.126B,227(1982)
B.A.Campbell,J.Ellis and S.Rudaz. Preprint CERN TH-3184(1981)
- [4] M.Jonker et al.(CHARM collab.) Phys.Lett.96B,435(1980)
- [5] V.Khovansky. 'Supersymmetry versus Experiment Workshop'.
Ref. TH.3311/EP.82/63 - CERN (1982) p.81
- [6] H.M.Georgi,S.L.Glashow,M.E.Machacek and D.V.Nanopoulos.
Annals of Physics 114,273(1978)
- [7] H.Abramowicz et al. Z.Phys.C 12,289(1982)

Fig.1

Fig.2

Fig.3