SEARCH FOR GLUINOS IN DECAYS OF THE $\chi_b(1^3P_1)$ MESON

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Using the ARGUS detector at the DORIS II e^+e^- storage ring, we have searched for gluinos ($\tilde{g}$), the supersymmetric partner of the gluon, by looking for secondary decay vertices in hadronic decays of $\chi_b(1\,^3P_1)$ mesons. Events containing $\chi_b(1\,^3P_1)$ states were selected by detecting the radiative transition from the $\Upsilon(2S)$ in a data set corresponding to an integrated luminosity of 38.6 pb^{-1}. The absence of secondary vertices from gluino decays into hadrons and a photino allows us to exclude gluinos in a mass range from 1 to 4.5 GeV/c^2 and a lifetime range from 10^{-11} to 10^{-9} s.

Supersymmetry [1] extends the invariance principles of gauge theories, by postulating a further symmetry in which every elementary boson has a supersymmetric fermion partner and vice versa. In such theories, for example, the gluon acquires a supersymmetric partner, the gluino ($\tilde{g}$), with spin 1/2, but otherwise identical quantum numbers. Since no evidence for any mass degenerate fermion–boson pairs has been observed, supersymmetry, if it exists at all, must be a broken symmetry. Various proposals for the scale and manner of symmetry breaking have been made, and, in particular, interesting supersymmetric models which lead to light gluinos can be constructed [2,3]. Beam-dump experiments [4] have searched for light gluinos by looking for photinos or goldstinos produced in gluino decays. Gluinos with lifetimes greater than 10^{-11} s cannot be detected by this means, since the premise that the gluino decays before being absorbed in the beam dump must be satisfied. No excess of muonless events has been seen beyond those expected from neutrino interactions, leading to constraints on allowed gluino and squark masses.

If, on the other hand, gluinos are relatively long-lived, then a direct search for gluino decay vertices can be made. In this paper, we report the results of such a complementary search for gluinos using the ARGUS detector at DORIS. For this purpose, we exploit the fact that the $\chi_b(1\,^3P_1)$, a bound state of b and $\bar{b}$ quarks, is a prolific source of gluinos [5], if the gluino mass is below 5 GeV/c^2. A data sample containing decays of the $\chi_b(1\,^3P_1)$ can be obtained by observing the radiative transition from the $\Upsilon(2S)$, produced in e^+e^- annihilation at a centre-of-mass energy of 10.023 GeV/c^2. Unlike the $\chi_b(1\,^3P_J)$, $J = 0, 2$ states, the $J = 1$ state cannot decay into two massless gluons, and instead principally proceeds via $gq\bar{q}$ [6] and $\gamma\Upsilon(1S)$. If gluinos exist in the mass range below 5 GeV/c^2, the decay $\chi_b(1\,^3P_1) \to g\tilde{g}\tilde{g}$ has a rate comparable to that for $\chi_b(1\,^3P_1) \to gq\bar{q}$ and is calculated from the same parton graph as shown in fig. 1a. Campbell et al. [5] find that

$$R_{\tilde{g}} = \frac{\mathrm{Br}[\chi_b(1\,^3P_1) \to g\tilde{g}\tilde{g}]}{\mathrm{Br}[\chi_b(1\,^3P_1) \to gq\bar{q}] + \mathrm{Br}[\chi_b(1\,^3P_1) \to g\tilde{g}\tilde{g}]} \quad (1)$$

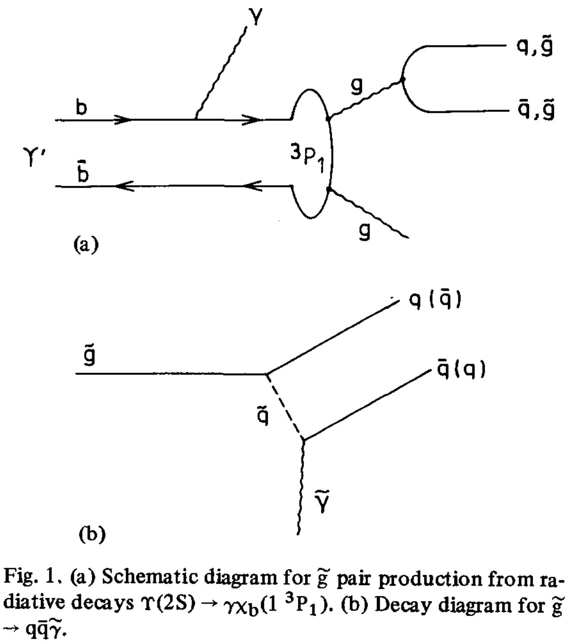

Fig. 1. (a) Schematic diagram for $\tilde{g}$ pair production from radiative decays $\Upsilon(2S) \to \gamma\chi_b(1\,^3P_1)$. (b) Decay diagram for $\tilde{g} \to q\bar{q}\tilde{\gamma}$.

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is 30% for gluino masses less than 3 GeV/c^2 and is still 10% for $m(\tilde{g})$ = 4.5 GeV/c^2. This result is independent of the fragmentation process for the gluinos into colour singlet states and of the decay modes of the gluino.

The hadronization of $g\tilde{g}\tilde{g}$ events produces charged and neutral R-hadrons [7], either gluonium-like $[\tilde{g}g]$ or hybrid-like $[\tilde{g}(q\bar{q})_8]$, in much the same way as normal hadrons are formed in $gq\bar{q}$ events. Ground state R-hadrons are produced at the end of the hadronization chain and traverse the detector as quasi-stable particles until the gluino decays. Such decays result in observable flight paths and detectable secondary vertices with two or more prongs, depending on the gluino mass and lifetime. The relationship between R-hadron and gluino masses and lifetimes is as complicated a problem as for ordinary hadrons, but presumably the masses and lifetimes of the former approach those of the latter with increasing gluino mass [8]. In order to model the R-hadron decays, and to determine the fraction of decays into two or more charged hadrons, one also has to assume a dominant decay mode for the gluino. This we take to be $q\bar{q}\tilde{\gamma}$, where $\tilde{\gamma}$ is the photino, proceeding by the exchange of a heavy scalar quark as shown in fig. 1b. In the limit of zero photino mass [9], this diagram yields a gluino lifetime of

$$\tau(\tilde{g}) = 1.2 \times 10^{-19}\,[m(\tilde{q})/(\mathrm{GeV}/c^2)]^4 \times [(\mathrm{GeV}/c^2)/m(\tilde{g})]^5\ \mathrm{s}\,, \qquad (2)$$

where $m(\tilde{q})$ is the mass of the squark and $\alpha_S = 0.17$ has been used. Thus, for example, the gluino will have a lifetime around 5×10^{-11} s for $m(\tilde{g}) \sim 1$ GeV/c^2 and $m(\tilde{q}) \sim 150$ GeV/c^2. If the photino mass is nonzero, the gluino lifetime is expected to be longer. Lifetimes of 5×10^{-11} s lead to mean flight paths of around 6 cm for $\chi_b(1\,^3P_1) \to g\tilde{g}\tilde{g}$ decays at rest.

A search for gluino decays has been made in 125 000 Υ(2S) events, representing an integrated luminosity of 38.6 pb^{-1}, collected using the ARGUS detector at the DORIS II e^+e^- storage ring. A short description of the detector, trigger conditions and multihadron selection criteria can be found in ref. [10]. The decays, $\Upsilon(2S) \to \gamma\chi_b(1\,^3P_1)$, were selected using the same procedure as described in ref. [11], that is by reconstructing those radiative photons which converted in the beam pipe or in the drift chamber inner wall. The energy spectrum of these photons is

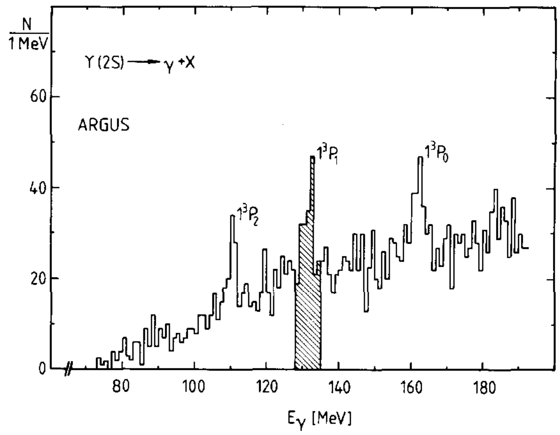

Fig. 2. Spectrum of converted photons from Υ(2S) decays taken from ref. [11]. The three prominant peaks correspond to transitions to the $\chi_b(1\,^3P_J)$, J = 0, 1, 2 states.

shown in fig. 2. Transitions to the $\chi_b(1\,^3P_1)$ are responsible for the second of the three visible photon lines, observed at an energy of (131.7 ± 0.3 ± 1.1) MeV with a resolution of $\sigma(E_\gamma)$ = 1.1 MeV. There are 210 $\chi_b(1\,^3P_1)$ candidates with E_γ between 128 and 135 MeV. After background subtraction, estimated by a fifth-order polynomial fit, we conclude that there are 65 decays of $\Upsilon(2S) \to \gamma\chi_b(1\,^3P_1)$ in this sample.

In all 210 candidate events, a search has been made for secondary vertices with 0 or 1 ingoing and $\geqslant 2$ outgoing charged particles, the decay signature for a long-lived neutral or charged R-hadron. To obtain a clean sample of such vertices, we have limited their range to between r = 1 and 60 cm, where r is the distance between the secondary vertex and the beam axis. The χ^2 value of the secondary vertex fit was required to be less than 30.

By this procedure, 39 vertices were found in the sample of $\chi_b(1\,^3P_1)$ events. Of these, 26 were identified as K_S^0 decays and 5 as Λ or $\bar{\Lambda}$ decays. The remaining 8 vertices were all in different events. We have scanned these events visually and find that three were due to interactions in the beam pipe or the compensation coil, and one was due to incorrect vertex reconstruction. The remaining four vertices contain a well-identified e^+ or e^-. Since we do not expect leptons from gluino decays, these events have been rejected; thus, there were no gluino candidates in our data sample.

The expected number of reconstructed secondary vertices from gluinos produced in the decay of 65

$\chi_b(1\,^3P_1)$ events, N_{SV}, has been estimated by Monte Carlo. Decays of $\chi_b(1\,^3P_1) \to g\tilde{g}\tilde{g}$ were generated on the parton level using the same matrix element as for $\chi_b(1\,^3P_1) \to gq\bar{q}$ [6]. The formation of R-hadrons was treated by assuming m(R-hadron) = $m(\tilde{g})$ and τ(R-hadron) = $\tau(\tilde{g})$. The weak decay $\tilde{g} \to q\bar{q}\tilde{\gamma}$ was described by a matrix element suitable for a decay proceeding by the exchange of a heavy scalar, as depicted in fig. 1b. The photino was assumed to be non-interacting, and the $q\bar{q}$ system was hadronized following the Field–Feynman method. Since the energy is limited, there is no pronounced jet structure and a phase space hadronization leads to very similar results.

The Monte Carlo calculation provides both the probability, $P_{\geqslant 2}(m)$, for the decay of a gluino with mass, $m = m(\tilde{g})$, into two or more charged particles (fig. 3a), and, from the product of the secondary vertex detection efficiency, $\eta_{SV}(m, l_0; l)$, and the trigger and event selection efficiency, $\eta_{DET}(m)$, the detection efficiency:

$$\eta(m, l_0) = l_0^{-1} \int_{1\,\mathrm{cm}}^{60\,\mathrm{cm}} \eta_{SV}(m, l_0; l)\exp(-l/l_0)\,\mathrm{d}l \times \eta_{DET}(m)\,, \tag{3}$$

where l_0 is the mean gluino flight path and l the actual distance between primary and secondary vertices. Contours of η in the m–l_0 plane are shown in fig. 3b. The efficiency is rather insensitive to the gluino mass, but rises rapidly from 10% to 40% as l_0 varies from 0.5 cm to 3 cm, and decreases slowly to 10% for l_0 around 30 cm. The direct detection efficiency, $\eta(m, l_0)$ can be transformed to a more useful dependence on m and τ using the gluino momentum spectrum given by the $\chi_b(1\,^3P_1) \to gq\bar{q}$ matrix element.

On the basis of these Monte Carlo results, the number of expected secondary vertices was calculated as follows:

$$N_{SV}(m, \tau) = 65\{1 - \mathrm{Br}[\chi_b(1\,^3P_1) \to \gamma\Upsilon(1S)]\} \times R_{\tilde{g}}(m) 2 P_{\geqslant 2}(m)\eta(m, \tau)\,, \tag{4}$$

where $R_{\tilde{g}}(m)$ has been defined above by eq. (1), and the factor of 2 accounts for the fact that there are two gluinos per $\chi_b(1\,^3P_1)$ decay. The contribution of gluinos from the cascade $\chi_b(1\,^3P_1) \to \gamma\Upsilon(1S)$, followed by $\Upsilon(1S) \to gg\tilde{g}\tilde{g}$ is negligible. The branching ratio for $\chi_b(1\,^3P_1) \to \gamma\Upsilon(1S)$ has been measured [12] to be (43 ± 11)%; in eq. (4), the more conservative value of 54%, one standard deviation above the mean, is used for the estimate of the minimal N_{SV}.

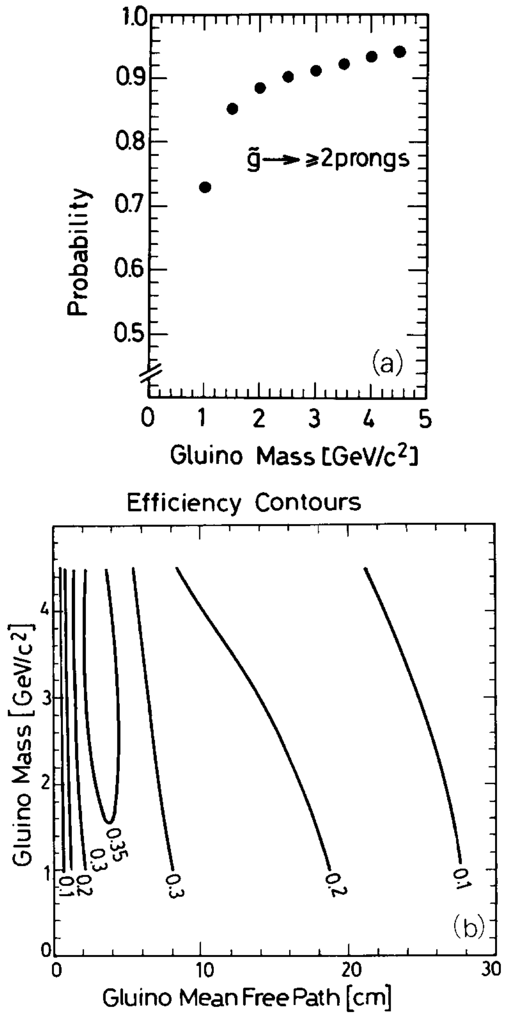

Fig. 3. (a) Probability for R-hadrons to decay into $\geqslant 2$ charged tracks as estimated by Monte Carlo assuming free gluino fragmentation into $q\bar{q}\tilde{\gamma}$. (b) Contour plots in the $m(\tilde{g})$–gluino mean free path (l_0) plane for the gluino detection efficiency as determined by Monte Carlo.

Having observed no candidates, a limit is placed on $R_{\tilde{g}}(m)$, which in turn leads to the excluded regions in the $m(\tilde{g})$–$\tau(\tilde{g})$ plane shown by the contours in fig. 4a. Based on Poisson statistics, the 90% contour corresponds to $N_{SV} = 2.3$ and 95% to $N_{SV} = 3.1$. In fig. 4b, these contours are transformed into the $m(\tilde{g})$–

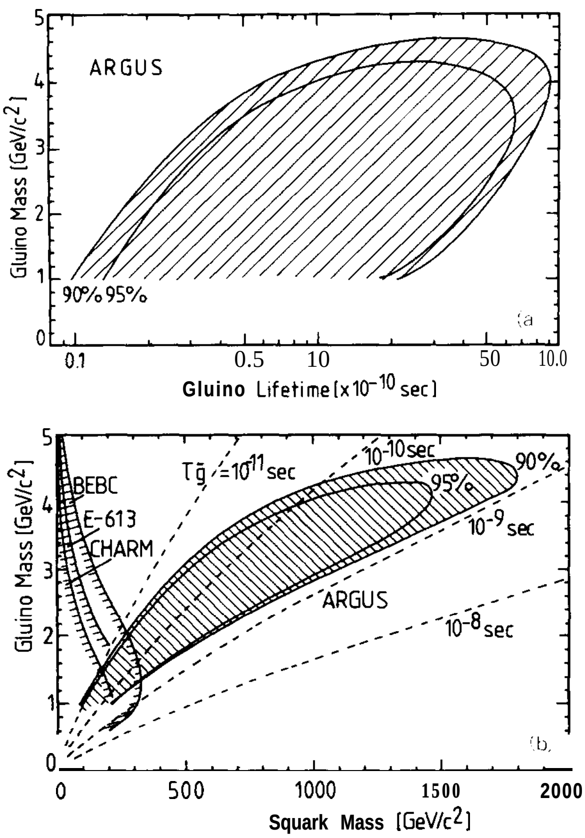

Fig. 4. (a) Excluded regions for gluinos as a function of gluino mass and lifetime, calculated, using eq. (1), from the limit placed on $R_{\tilde{g}}(m)$ by the nonobservation of gluino decays in the $\chi_b(1\,^3P_1)$ sample. (b) Excluded regions for gluinos as a function of gluino mass and squark mass, calculated using eq. (2).

$m(\tilde{q})$ plane, using the lifetime estimate given by eq. (2) in the zero-mass approximation for the photino. For comparison, the regions excluded by beam-dump experiments are also shown.

In conclusion, we have used 65 $\chi_b(1\,^3P_1)$ decays to exclude the existence of gluinos with mass between 1.0 and 4.5 GeV/c^2 in a gluino lifetime or squark mass range which complements the ranges excluded by the results from beam-dump experiments. At a typical gluino mass of 3 GeV/c^2, gluino lifetimes between 3 X 10^{-11} s and 7 X 10^{-10} s, corresponding to squark masses between 530 and 1050 GeV/c^2, are excluded at the 90% confidence level.

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