DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 85-129
November 1985

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

by

ARGUS Collaboration

ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY 85-129
November 1985
ISSN 0418-9833

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

THE ARGUS COLLABORATION

H. ALBRECHT, U. BINDER, G. HARDER, I. LEMBKE-KOPPITZ, A. PHILIPP, W. SCHMIDT-PARZEFALL, H. SCHRÖDER, H.D. SCHULZ, R. WURTH
DESY, HAMBURG, GERMANY

J.P. DONKER, A. DRESCHER, U. MATTHIESEN, H. SCHECK, B. SPAAN, J. SPENGLER, D. WEGENER
INSTITUT FÜR PHYSIK, UNIVERSITÄT DORTMUND[1], GERMANY

J.C. GABRIEL, K.R. SCHUBERT, J. STIEWE, R. WALDI, S. WESELER
INSTITUT FÜR HOCHENERGIEPHYSIK, UNIVERSITÄT HEIDELBERG[1], GERMANY

N.N. BROWN[2], K.W. EDWARDS[3], W.R. FRISKEN[4], CH. FUKUNAGA[4], D.J. GILKINSON[5], D.M. GINGRICH[5], M. GODDARD[4], H. KAPITZA[3], P.C.H. KIM[5], R. KUTSCHKE[5], D.B. MACFARLANE[5], J.A. MCKENNA[5], K.W. MCLEAN[2], A.W. NILSSON[2], R.S. ORR[5], P. PADLEY[5], P.M. PATEL[2], J.D. PRENTICE[5], H.C.J. SEYWERD[5], B.J. STACEY[5], T.-S. YOON[5], J.C. YUN[3]
INSTITUTE OF PARTICLE PHYSICS[6], CANADA

R. AMMAR, D. COPPAGE, R. DAVIS, S. KANEKAL, N. KWAK
UNIVERSITY OF KANSAS[7], LAWRENCE, KANSAS, USA

G. KERNEL, M. PLEŠKO
J. STEFAN INSTITUTE AND DEPARTMENT OF PHYSICS, UNIVERSITY OF LJUBLJANA[8], YUGOSLAVIA

L. JÖNSSON, Y. OKU
INSTITUTE OF PHYSICS, UNIVERSITY OF LUND[9], SWEDEN

A. BABAEV, M. DANILOV, A. GOLUTVIN, V. LUBIMOV, V. MATVEEV, V. NAGOVITSIN, V. RYLTSOV, A. SEMENOV, V. SHEVCHENKO, V. SOLOSHENKO, V. SOPOV, I. TICHOMIROV, YU. ZAITSEV
INSTITUTE OF THEORETICAL AND EXPERIMENTAL PHYSICS, MOSCOW, USSR

R. CHILDERS, C.W. DARDEN, AND H. GENNOW[10]
UNIVERSITY OF SOUTH CAROLINA[11], COLUMBIA, S.C., USA

[1]Supported by the Bundesministerium für Forschung und Technologie, Federal Republic of Germany.
[2]McGill University, Montreal.
[3]Carleton University, Ottawa.
[4]York University, Downsview.
[5]University of Toronto, Toronto.
[6]Supported by the Natural Sciences and Engineering Research Council, Canada.
[7]Supported by the U.S. National Science Foundation and a University of Kansas Faculty Improvement award.
[8]Supported in part by the Internationales Büro KfA, Jülich and DESY, Hamburg.
[9]Supported by the Swedish Research Council.
[10]Now at the University of Stockholm, Sweden.
[11]Supported by the U.S. Department of Energy, under contract DE-AS09-80ER10690.

ABSTRACT

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} sec.

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} sec 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 $\chi_b(1^3P_1) \rightarrow g\tilde{g}\tilde{g}$ has a rate comparable to that for $\chi_b(1^3P_1) \rightarrow gq\bar{q}$ and is calculated from the same parton graph as shown in figure 1a. Campbell et al.[5] find that

$$R_{\tilde{g}} = \frac{Br[\chi_b(1^3P_1) \rightarrow g\tilde{g}\tilde{g}]}{Br[\chi_b(1^3P_1) \rightarrow gq\bar{q}] + Br[\chi_b(1^3P_1) \rightarrow g\tilde{g}\tilde{g}]} \qquad (1)$$

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 figure 1b. In the limit of zero photino mass[9], this diagram yields a gluino lifetime of:

$$\tau(\tilde{g}) = 1.2 \times 10^{-19} \left(\frac{m(\tilde{q})}{GeV/c^2}\right)^4 \left(\frac{GeV/c^2}{m(\tilde{g})}\right)^5 \qquad (2)$$

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 $5 \cdot 10^{-11}$ sec for $m(\tilde{g}) \sim 1$ GeV/c^2 and $m(\tilde{q}) \sim 150$ GeV/c^2. If the photino mass is non-zero, the gluino lifetime is expected to be longer. Lifetimes of $5 \cdot 10^{-11}$ sec lead to mean flight paths of around 6 cm for $\chi_b(1^3P_1) \rightarrow g\tilde{g}\tilde{g}$ decays at rest.

A search for gluino decays has been made in 125000 $\Upsilon(2S)$ 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 reference 10. The decays, $\Upsilon(2S) \rightarrow \gamma\chi_b(1^3P_1)$, were selected using the same procedure as described in reference 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 shown in figure 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 $(131.7 \pm 0.3 \pm 1.1)$ 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 $\Upsilon(2S) \rightarrow \gamma\chi_b(1^3P_1)$ in this sample.

In all 210 candidate events, a search has been made for secondary vertices with 0 or 1 ingoing and ≥ 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^0_S 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 $\chi_b(1\,^3P_1) \rightarrow \tilde{g}\tilde{g}\tilde{g}$ were generated on the parton level using the same matrix element as for $\chi_b(1\,^3P_1) \rightarrow gq\overline{q}$[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 $\tilde{g} \rightarrow q\overline{q}\tilde{\gamma}$ was described by a matrix element suitable for a decay proceeding by the exchange of a heavy scalar, as depicted in figure 1b. The photino was assumed to be non-interacting, and the $q\overline{q}$ 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, $P_{\geq 2}(m)$, for the decay of a gluino with mass, $m = m(\tilde{g})$, into two or more charged particles (figure 3a), and, from the product of the secondary vertex detection efficiency, $\eta_{SV}(m, \ell_0; \ell)$, and the trigger and event selection efficiency, $\eta_{DET}(m)$, the detection efficiency:

$$\eta(m, \ell_0) = \ell_0^{-1} \int_{1\ \mathrm{cm}}^{60\ \mathrm{cm}} \eta_{SV}(m, \ell_0; \ell)\, e^{-\ell/\ell_0}\, d\ell \cdot \eta_{DET}(m) \qquad (3)$$

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 figure 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, $\eta(m, \ell_0)$ can be transformed to a more useful dependence on m and τ using the gluino momentum spectrum given by the $\chi_b(1\,^3P_1) \rightarrow gq\overline{q}$ matrix element.

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

$$N_{SV}(m, \tau) = 65 \cdot [1 - Br[\chi_b(1\,^3P_1) \rightarrow \gamma\Upsilon(1S)]] \cdot R_{\tilde{g}}(m) \cdot 2 \cdot P_{\geq 2}(m) \cdot \eta(m, \tau) \qquad (4)$$

where $R_{\tilde{g}}(m)$ has been defined above by equation 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 $\chi_b(1\,^3P_1) \rightarrow \gamma\Upsilon(1S)$, followed by $\Upsilon(1S) \rightarrow gg\tilde{g}\tilde{g}$ is negligible. The branching ratio for $\chi_b(1\,^3P_1) \rightarrow \gamma\Upsilon(1S)$ has been measured[12] to be (43 ± 11)%; in equation 4, the more conservative value of 54%, one standard deviation above the mean, is used for the estimate of the minimal N_{SV}.

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 figure 4a. Based on Poisson statistics, the 90% contour corresponds to $N_{SV} = 2.3$ and 95% to $N_{SV} = 3.1$. In figure 4b, these contours are transformed into the $m(\tilde{g})$-$m(\tilde{q})$ plane, using the lifetime estimate given

by equation 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 $3 \cdot 10^{-11}$ sec and $7 \cdot 10^{-10}$ sec, corresponding to squark masses between 530 and 1050 GeV/c^2, are excluded at the 90% confidence level.

ACKNOWLEDGEMENTS

It is a pleasure to thank E.Michel, W.Reinsch, Dr.K.Rauschnabel, Mrs.U.Djuanda and Mrs.E.Konrad for their competent technical help in running the experiment and processing the data. We thank Drs.H.Nesemann, K.Wille and the DORIS group for the good operation of the storage ring. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them.

FIGURE CAPTIONS

Figure 1a Schematic diagram for $\tilde{g}$ pair production from radiative decays $\Upsilon(2S) \rightarrow \gamma\chi_b(1\,^3P_1)$.

Figure 1b Decay diagram for $\tilde{g} \rightarrow q\bar{q}\tilde{\gamma}$.

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

Figure 3a Probability for R-hadrons to decay into ≥ 2 charged tracks as estimated by Monte Carlo assuming free gluino fragmentation into $q\bar{q}\tilde{\gamma}$.

Figure 3b Contour plots in the $m(\tilde{g})$-gluino mean free path (ℓ_0) plane for the gluino detection efficiency as determined by Monte Carlo.

Figure 4a Excluded regions for gluinos as a function of gluino mass and lifetime, calculated, using equation 1 in the text, from the limit placed on $R_{\tilde{g}}(m)$ by the non-observation of gluino decays in the $\chi_b(1\,^3P_1)$ sample.

Figure 4b Excluded regions for gluinos as a function of gluino mass and squark mass, calculcated using equation 2 in the text.

REFERENCES

(1) Yu.A.Gol'fand and E.P.Likhtman, JETP Letters **13** (1971) 323;
D.V.Volkov and V.P.Akulov, Phys.Lett. **46B** (1973) 109;
J.Wess and B.Zumino, Nucl.Phys. **B70** (1974) 39; Phys.Lett. **49B** (1974) 52;
Nucl.Phys. **B78** (1974) 1.

(2) P.Fayet and J.Iliopoulos, Phys.Lett. **51B** (1974) 461;
P.Fayet, Phys.Lett. **78B** (1978) 417

(3) E.Witten, Nucl.Phys. **B188** (1981) 513;
S.Dimopoulos and S.Raby, Nucl.Phys. **B192** (1981) 353;
M.Dine, W.Fischler and M.Srednicki, Nucl.Phys. **B189** (1981) 575.

(4) F.Bergsma et al. (CHARM collaboration), Phys.Lett. **121B** (1983) 429;
R.C.Ball et al. (E613 collaboration), Phys.Rev.Lett. **53** (1984) 1314.
A.M.Cooper-Sarkar et al. (BEBC/WA66 collaboration), CERN preprint CERN/EP 85-97 (1985).

(5) B.A.Campbell, J.Ellis and S.Rudaz, Nucl.Phys. **B198** (1982) 1.

(6) R.Barbieri and R.Gatto, Phys.Lett. **61B** (1976) 465;
R.Barbieri, M.Caffo and E.Remiddi, Phys.Lett. **83B** (1979) 345.

(7) G.R.Farrar and P.Fayet, Phys.Lett. **76B** (1978) 575.

(8) E.Franco, Phys.Lett. **124B** (1983) 271;
M.Chanowitz and S.Sharpe, Phys.Lett. **126B** (1983) 225;
H.E.Haber and G.L.Kane, Phys.Rep. **117** (1985) 75.

(9) G.L.Kane and J.P.Leveille, Phys.Lett. **112B** (1982) 227;
H.E.Haber and G.L.Kane, Nucl.Phys. **B232** (1984) 333.

(10) H.Albrecht et al. (ARGUS collaboration), Phys.Lett. **134B** (1984) 137.

(11) H.Albrecht et al. (ARGUS collaboration), Phys.Lett. **160B** (1985) 331;
A.Philipp, Ph.D. Thesis, University of Dortmund (1985).

(12) C.Klopfenstein et al. (CUSB collaboration), Phys.Rev.Lett. **51** (1983) 160;
F.Pauss et al. (CUSB collaboration), Phys.Lett. **130B** (1983) 439.

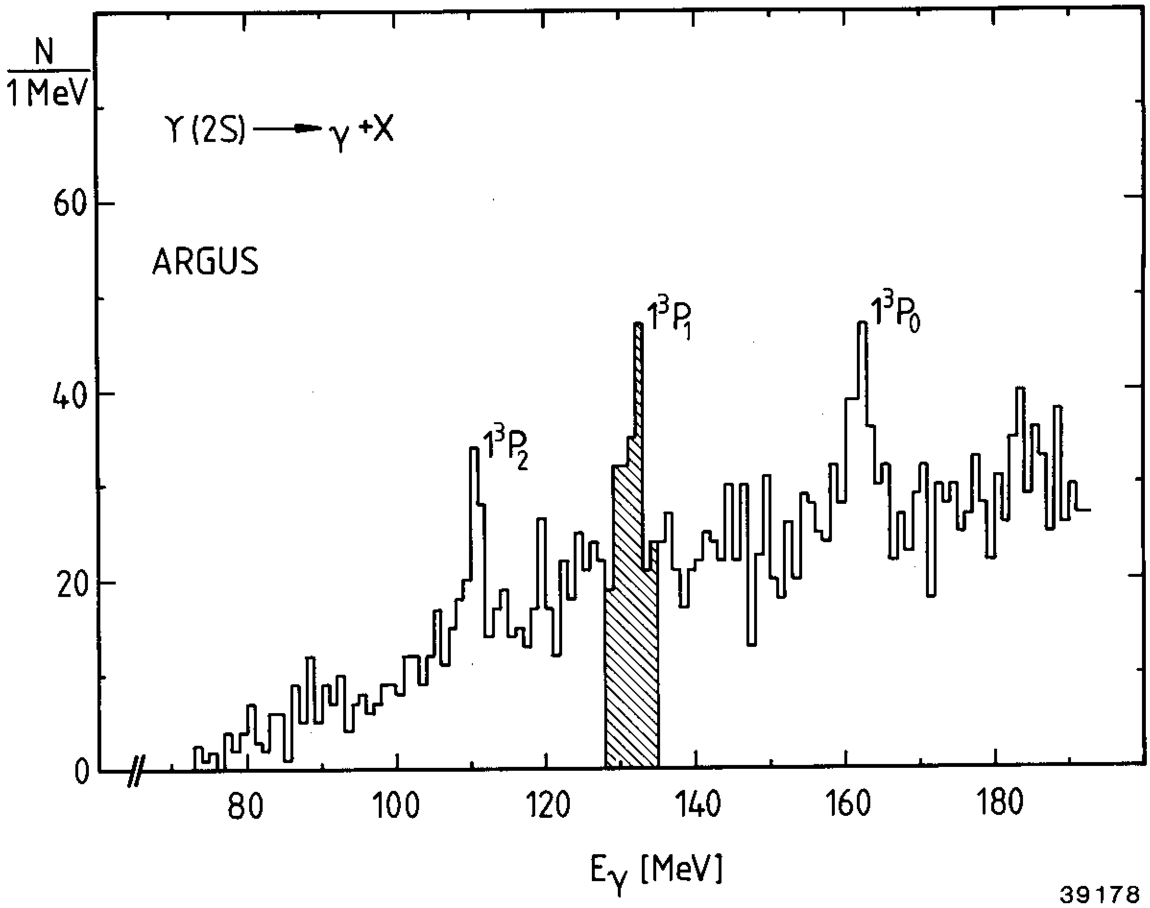

Figure 2

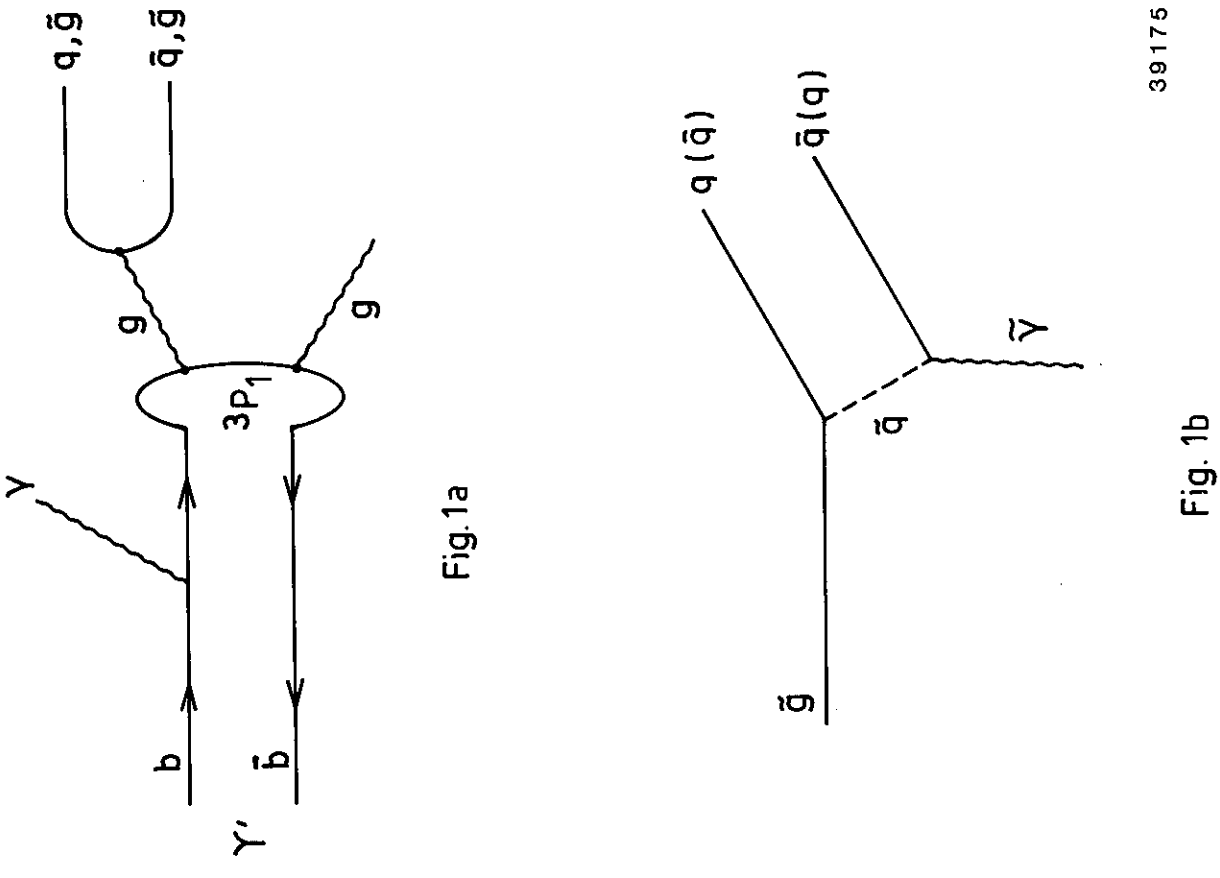

Fig.1a

Fig. 1b

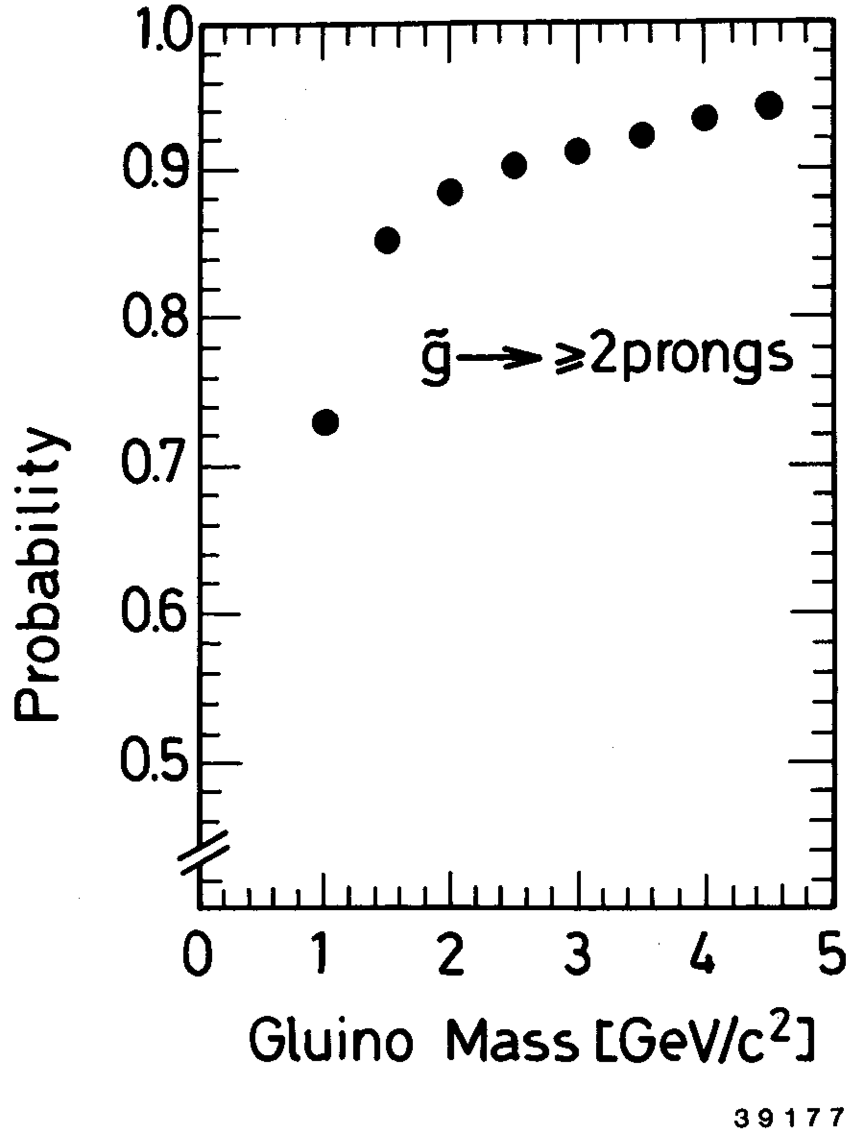

Figure 3a

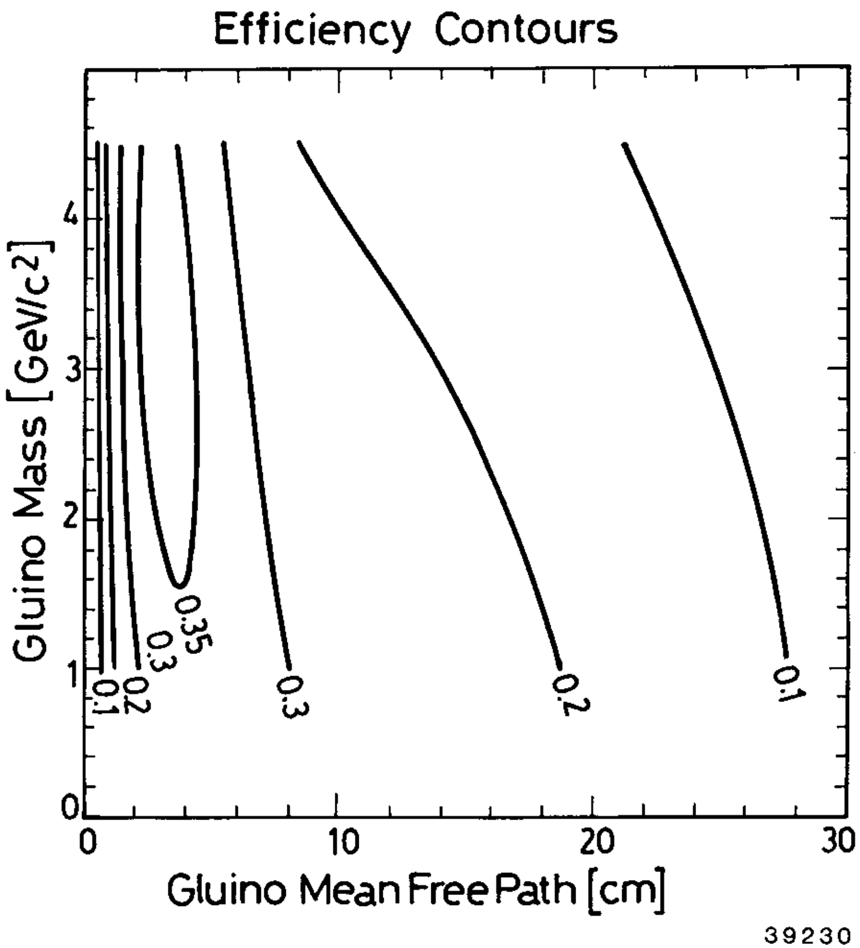

Figure 3b

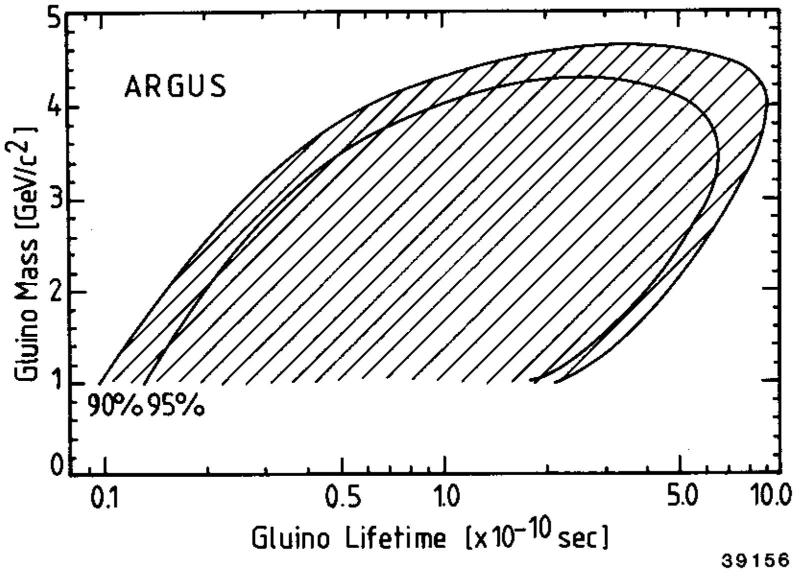

Figure 4a

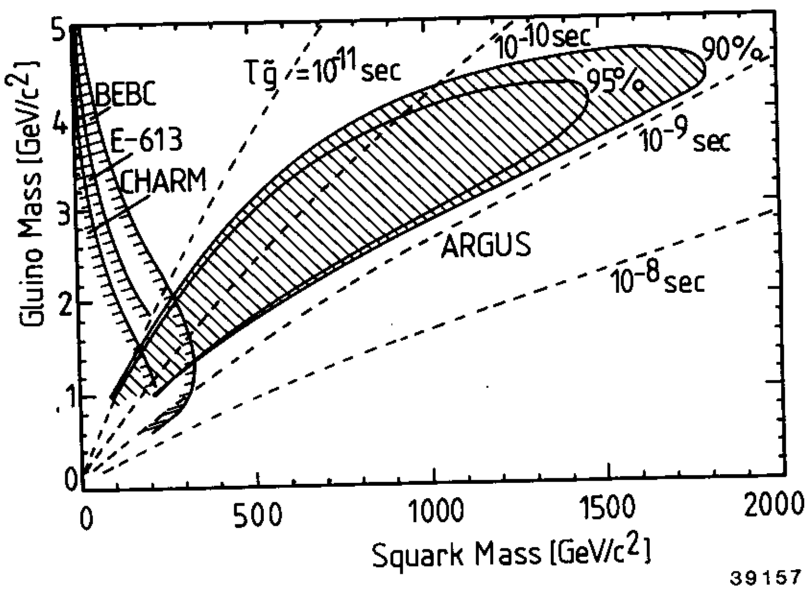

Figure 4b