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Light, long-lived and secluded: can gluinos be driven out from LEP1 data ?

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Abstract

We briefly report about a possible settlement of the still ongoing dispute concerning the existence of SUSY signals in 4jet events at LEP1. We base our arguments on a simple selection strategy exploiting secondary vertex tagging and kinematical constraints, which could allow one to access or exclude gluino events for a broad range of masses and lifetimes.

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Introduction

If the results of the LEP1 measurements were pieces of a jigsaw puzzle reproducing the edifice of the Standard Model, then one could well question that some of these are apparently not so perfectly shaped, i.e., they fit into their original location only with some effort. This is certainly the case for the determination of Γ_c and Γ_b, the partial widths of the Z into c and b quarks, for which claims of Supersymmetry (SUSY) hints have been made [1]. Indeed, there is another controversy still open along the same lines. Somewhat less glamorous but not for this less important is the possibility of gluino events being present in 4-jet decays [2, 3].

The story goes as follows. The colour factors C_A, C_F and T_F of QCD [4] can be measured by fitting some angular distributions[1] whose shape significantly depends on the partonic composition of the α_s^2 decays of the Z. Then one obtains that, although the experimental measurements agree well with ordinary QCD, it is not possible to rule out its Supersymmetric version, which predicts that light gluinos $\tilde{g}$ (the SUSY partners of the gluons) can be produced at LEP1 energies [3]. In detail, gluinos with a mass $m_{\tilde{g}} \gtrsim 2$ GeV yield an expectation value for T_F/C_F that is within one standard deviation of the measured one [3]. In fact, if the gluino mass is light enough [6], such particles should be produced in the process $e^+e^- \to Q\bar{Q}\tilde{g}\tilde{g}$ via a $g^* \to \tilde{g}\tilde{g}$ splitting [7, 8]. Since gluinos are coloured fermions, such events would enter into the sample with a behaviour similar to that of $Q\bar{Q}q\bar{q}$ events. Naively, one could well say that the total number of flavours N_F of the theory is apparently increased, such that, a SUSY signal reveals itself as an enhancement of $T_R \equiv N_F T_F$. Such kind of new particles are at present still compatible with the experiments [9, 10].

The reason why experiments have not given a conclusive answer so far is that both systematical (hadronisation, higher order perturbative corrections) and statistical (4-jet decays constitute only $\lesssim 10\%$ the hadronic sample) errors spoil considerably the precision of the measurements, thus preventing one from putting stringent bounds on C_A, C_F and T_R. However, the most serious and *intrinsic* limitation of the analyses performed up to now is that they made use of energy ordering to distinguish between quark and gluon jets and to assign the momenta to the final state partons[2].

A clear improvement to this approach is the one proposed in Ref. [12]. There, it was shown the superiority of using 4-jet samples in which two jets are tagged as b-jets. In this way, one gets a greater discrimination power between $Q\bar{Q}gg$ and $Q\bar{Q}q\bar{q}$ events. First, because this way one is able to distinguish between quarks and gluons, thus assigning the momenta correctly. Second, because gluon rates are reduced by almost a factor of 2 with respect to the quark ones, such that differences between the two partonic components can be more easily investigated. Following Ref. [12], the LEP Collaborations have recently performed new studies [13, 14], whose preliminary results show indeed that SUSY predictions can be more efficiently constrained. Furthermore, they have proved that adopting a double vertex tag[3] does not ruin the advantages gained with particle identification.

Besides the final results of these new, improved analyses, we want to stress that there are other possibilities offered by the μ-vertex devices, that can be exploited in order to either confirm or disprove the presence of SUSY signals in 4-jet events. This is apparent if one notices that

[1] That is, the angles of Bengtsson-Zerwas, of Körner-Schierholz-Willrodt, of Nachtmann-Reiter and that between the two least energetic jets [5].

[2] The two most energetic jets are identified as primary quarks. Unfortunately, for $Q\bar{Q}gg$ events, in only half of the cases the two lowest energy partons are both gluons [11] !

[3] Which reduces considerably the statistical sample, as the current efficiency at LEP1 in tagging a displaced vertex is $\varepsilon \approx 30\%$ per jet.

light gluinos can also be relatively long-lived, such that they might produce detectable secondary vertices [15]. It is the purpose of this letter to study to which extent such experimental techniques can be used for detecting or ruling out SUSY signals at LEP1, even when no special effort is made to distinguish between displaced vertices due to b-quarks and to gluinos.

The plan of the paper is as follows. In the next Section we describe our calculations, in Section 3 we discuss the results, and in Section 4 we summarise and conclude.

2. Calculation

In carrying out the study described here we made use of the FORTRAN matrix elements already discussed in Ref. [16] and presently used for experimental simulations [3], upgraded with the inclusion of the gluino production and decay mechanisms (see also Ref. [17])[4]. The programs do not contain any approximations, the intermediate states γ^* and Z being both inserted, and the masses and polarisations of all particles in the final states (of the two-to-four body processes) retained. The availability of the last two options is especially important if one considers, on the one hand, that in b-tagged samples all final states are massive, and, on the other hand, that in proceeding to experimental fits one could well select restricted regions of the differential spectra of the angular variables, where the rates are likely to strongly depend on the spin state of the partons[5].

As jet finding algorithm we have adopted here the Durham (D) scheme [18]. However, none of the results drastically depends on the choice of the jet recombination procedure and/or the value of the jet resolution parameter, $y_{\rm cut}$. Finally, to make clear the rest of the paper, we use the following notation: when heavy flavour identification is implied, labels 1 & 2 refer to the two tagged jets and 3 & 4 to the two remaining ones. If no vertex tagging is assumed, jets are labelled according to their energy, $E_1 \geq E_2 \geq E_3 \geq E_4$.

3. Results

3.1 Gluino tagging

When dealing with tagging a secondary vertex possibly due to gluino decays, several points must be addressed. First of all, one has to confine oneself to secondary vertex analyses only[6], however this technique has a larger efficiency than any other method [19]. Second, the vertex has to be inside the detectors, so that only gluinos with $\tau_{\tilde{g}} \lesssim 10^{-9}$ s can be searched for [15]. Nonetheless, this represents an appealing opportunity, as a substantial part of the $(m_{\tilde{g}}, \tau_{\tilde{g}})$ window [7] not yet excluded by the experimental data could be covered. The latest constraints still allow for the existence of relatively long-lived and light gluinos, in the parameter regions: (i) $m_{\tilde{g}} \lesssim 1.5$ GeV and $\tau_{\tilde{g}} \lesssim 10^{-8}$ s; (ii) $m_{\tilde{g}} \gtrsim 4$ GeV and $\tau_{\tilde{g}} \gtrsim 10^{-10}$ s [9, 10].

In this respect, we exploit a sort of 'degeneracy' in lifetime between b-quarks and gluinos, assuming that when making secondary vertex tagging one naturally includes in the $2b2$jet sample also SUSY events, in which a $\tilde{g}$ behaves as a b. We call such approach 'minimal trigger'

[4]The numerical values adopted for quark masses and $\mathcal{SM}$ parameters can be found in Ref. [16].

[5]For this reason we have not used the results published in literature for the gluino decay rates, as these are averaged over the helicities of the unstable particle. Instead we have recomputed the relevant Feynman decay amplitudes by preserving the gluino polarisation and by matching the latter with the corresponding one in the production process.

[6]Thus neglecting other forms of heavy flavour tagging: such as the high p_T lepton method, as gluinos do not decay semileptonically.

procedure, as we propose a tagging strategy that does not take into account any of the possible differences between gluinos and b-quarks in 4-jet events with two secondary vertices (thus, in the following, we will generally speak of 'vertex tagging'). There are in fact at least three obvious dissimilarities.

(i) Their charge is different, such that one could ask that the jet showing a displaced vertex has a null charge. This would allow one to isolate a sample of pure SUSY events. However, we remind the reader that measuring the charge of a low energy jet in 4-jet events would have very low efficiency (in isolating a very broad hadronic system in an environment with high hadronic multiplicity) and has not has not been attempted before.

(ii) Gluino lifetimes much longer than b-lifetimes are still consistent with experiment (note that $\tau_b \approx 10^{-12}$ s), such that recognising a displaced vertex with decay length $d \gg 3$ mm (that of the b) would allow one to immediately identify gluinos. Unfortunately, most of the b-tagged hadronic sample at LEP1 has been collected via a bi-dimensional tagging (see, e.g., Ref. [20]). Thus, different d's could well appear the same on the event plane. Furthermore, tagging a $d > 3$ mm vertex would allow one to separate gluinos with $\tau_{\tilde{g}} > \tau_b$, but this would not be helpful if $\tau_{\tilde{g}} \leq \tau_b$.

(iii) Other than in lifetime, b-quarks and gluinos can differ in mass as well, such that one might attempt to exploit mass constraints to separate SUSY and pure QCD events. However, on the one hand, one could face a region of m_b-$m_{\tilde{g}}$ degeneracy and, on the other hand, one should cope with the ambiguities related to the concept of mass as defined at partonic level and as measured at hadron level.

We emphasise that measuring the charge of the vertex tagged jet, attempting to disentangle different decay lengths or measuring partonic masses could well be further refinements of the procedure we are proposing. These could be implemented at a later stage without spoiling the validity of our approach. In addition, all these aspects would necessaril need a proper experimental analysis, which is beyond the scope of a theoretical study.

The steps of our procedure are very simple. Under the assumption that b's and $\tilde{g}$'s are not distinguishable by vertex tagging, one naturally retains in the sample all SUSY events, whereas the ordinary QCD components are reduced by a factor of 5 ($Q\bar{Q}gg$) and 3 ($Q\bar{Q}q\bar{q}$). Then, it is easy to notice that there exist clear kinematic differences between the $Q\bar{Q}gg$, $Q\bar{Q}q\bar{q}$ and $Q\bar{Q}\tilde{g}\tilde{g}$ components. This is shown in Fig. 1, where we plot the quantities $Y_{ij} = M_{ij}^2/s \equiv (p_i + p_j)^2/s$, where $ij = 12$ or 34 and $s = M_Z^2$. The behaviour of the curves is dictated by the fact that gluinos are always secondary products in 4-jet events, whereas quarks and gluons are not (lower plots). When no vertex tagging is exploited and the common energy ordering is performed, such differences are washed away (upper plots). The value $m_{\tilde{g}} = 5$ GeV is assumed for reference, the shape of the distributions being qualitatively the same regardless of it. Therefore, if one simply asks to reject events for which, e.g., $Y_{12} > 0.2$ and/or $Y_{34} < 0.1$, one gets for the total rates of the three components the pattern depicted in Fig. 2. Notice that the drastic predominance of $2Q2g$ events in the complete 'unflavoured' sample has disappeared. Further, the total rates of ordinary QCD events are significantly reduced compared to those of SUSY events (after vertex tagging, top right), and eventually the $Q\bar{Q}\tilde{g}\tilde{g}$ fraction is always comparable to that of $Q\bar{Q}gg + Q\bar{Q}q\bar{q}$ events (when also the kinematics cut are implemented, bottom left). Most important, this is true *independently* of the gluino mass, of the jet algorithm and of the $y_{\rm cut}$ value used in the analysis.

Therefore, after our event selection, SUSY signals would certainly be identifiable, as a clear excess in the total number of 4-jet events with two displaced vertices. Thus, the presence of gluinos at LEP1 could be revealed or excluded at least over appropriate regions of masses and lifetimes[7]. We finally stress that, as we are concerning here with total rates and not with differential distributions, the event number should be sufficient to render the analysis statistically significant[8]. Furthermore, the ambiguities related to the fact that gluino effects on the total number of 4-jet events are comparable in percentage to the systematic uncertainties due to the jet hadronisation process and/or the $y_{\rm cut}$ selection procedure are much less severe in ours than in the usual approach [9]. However, since the key point of the present study is to exploit the $b/\tilde{g}$ vertex degeneracy, a highly enriched heavy flavour sample should be selected in this case.

3.2 Gluino decays

Before closing, we should mention that a further aspect must be kept into account when attempting our analysis. It concerns the kinematics of the gluino decays. In the most widely supported SUSY framework [22], the dominant gluino decay modes are $\tilde{g} \to q\bar{q}\tilde{\gamma}$ and $\tilde{g} \to g\tilde{\gamma}$, where $\tilde{\gamma}$ represents a 'photino' (better, the Lightest Supersymmetric Particle, which is a superposition of the SUSY partners of the neutral gauge bosons of the theory). Furthermore, the $q\bar{q}\tilde{\gamma}$ channel is, in general, largely dominant over the $g\tilde{\gamma}$ mode [23].

The crucial point is that in both cases the gluino decays into a jet with missing energy. It is not our intention to discuss the possibility of selecting such a signature, as we are mainly concerned here with the fact that the energy left to the hadronic system E_h is above the experimental cuts in minimal hadronic energy, which are used to reduce the backgrounds (e.g., in Ref. [3] the threshold was set equal to 3 GeV). In Fig. 3 (first three plots) we show the E_h spectra after the gluino decay, in both the channels. Two kinematic decay configurations are considered: a massless photino, and a massive one (i.e., $m_{\tilde{\gamma}} = 1/2 m_{\tilde{g}}$). The message is that in the most likely SUSY scenario (i.e., three-body decay dominant and massless photino) all gluino events should be retained in the event selection. Conversely, the figure illustrates the percentage of these which will pass the adopted trigger requirements. Finally, in the bottom right plot of Fig. 3 we show the dependence of the SUSY rates on the value of $m_{\tilde{g}}$. Below $m_{\tilde{g}} \approx 5$ GeV, the mass suppression is always less than a factor of 2.

4. Summary and conclusions

In this paper we have stressed the importance of using at LEP1 samples of 4-jet events in which two of the jets show a displaced vertex, and of adopting simple invariant mass cuts based on the different kinematics of partons in the final state. This can help to settle down the ongoing dispute about the existence of SUSY events in the data, at least for a wide range of gluino masses and lifetimes. Those presented are theoretical results, which should be in the end verified by detailed MC simulations that could even improve our event selection strategy (by exploiting differences between b's and $\tilde{g}$'s, in charge, mass and lifetime). Therefore, it is our opinion that the matter raised and procedures similar to the ones outlined here would deserve experimental attention. An enlarged and more detailed version of the present paper, which contains a generalisation of our results to other three jet schemes together with a discussion of

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[7] And this should certainly be done after the appropriate MC simulations, including the details of the detectors and of the tagging procedure as well as a generator where $m_{\tilde{g}}$ and $\tau_{\tilde{g}}$ enter as free parameters to be determined by a fit.

[8] In this respect we acknowledge that many of the aspects of our approach were already employed in Ref. [15], however the tagging procedure sketched there is well beyond the statistical possibilities of the LEP1 experiments.

[9] These are in fact the underlying difficulties of any analysis based on the 'unflavoured' hadronic sample and/or the jet energy ordering, which have not been overcome even in recent improved analyses [21].

the angular variable dependence of the ordinary QCD and SUSY rates, will be given elsewhere [24].

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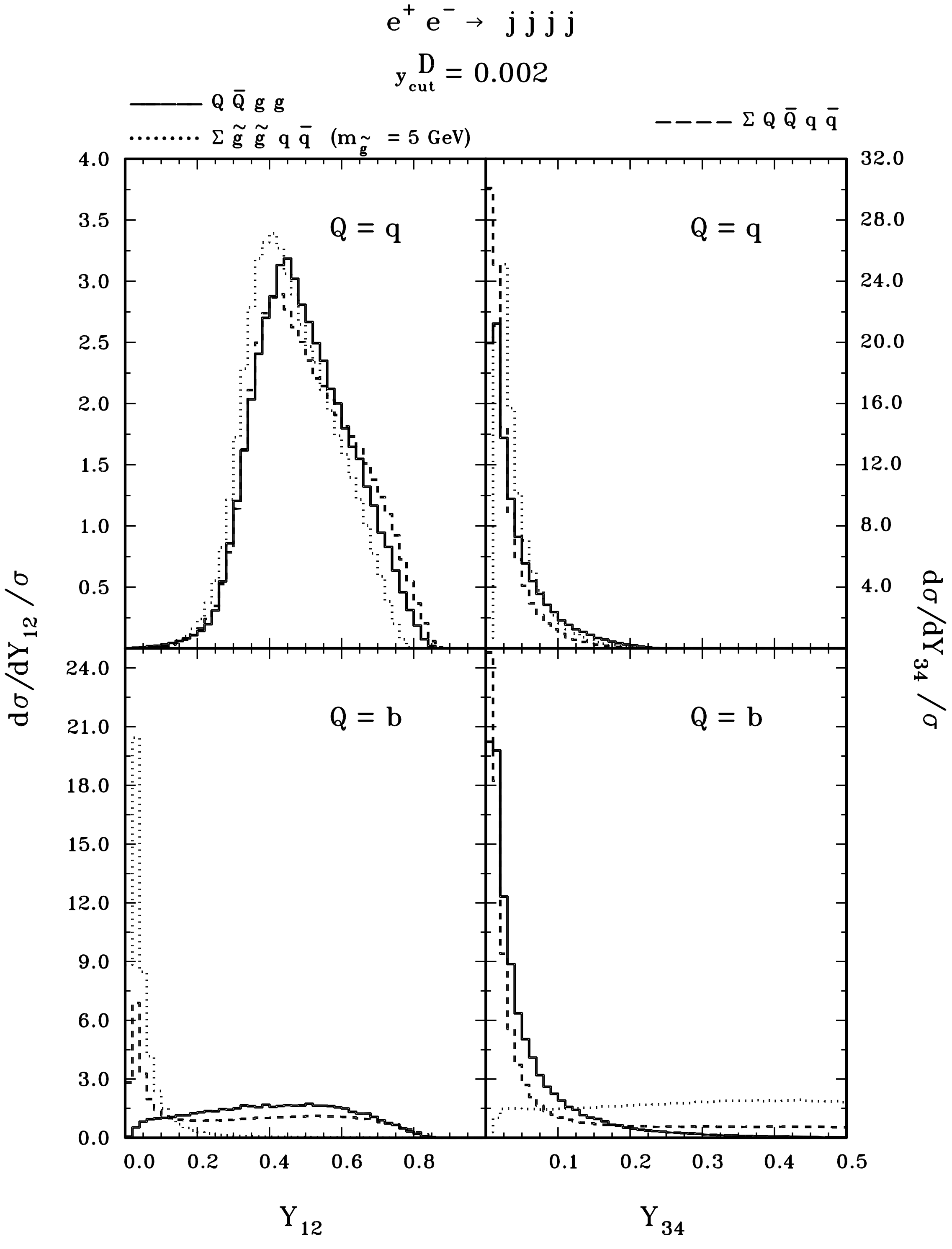

Fig. 1

Distributions in the rescaled invariant masses $Y_{ij} = M_{ij}^2/s$, where $ij = 12, 34$, for ordinary QCD and for SUSY 4-jet events, in the D scheme with $y_{\rm cut}^D = 0.002$, without $(Q = q)$ and with $(Q = b)$ vertex tagging. Here, $m_{\tilde g} = 5$ GeV.

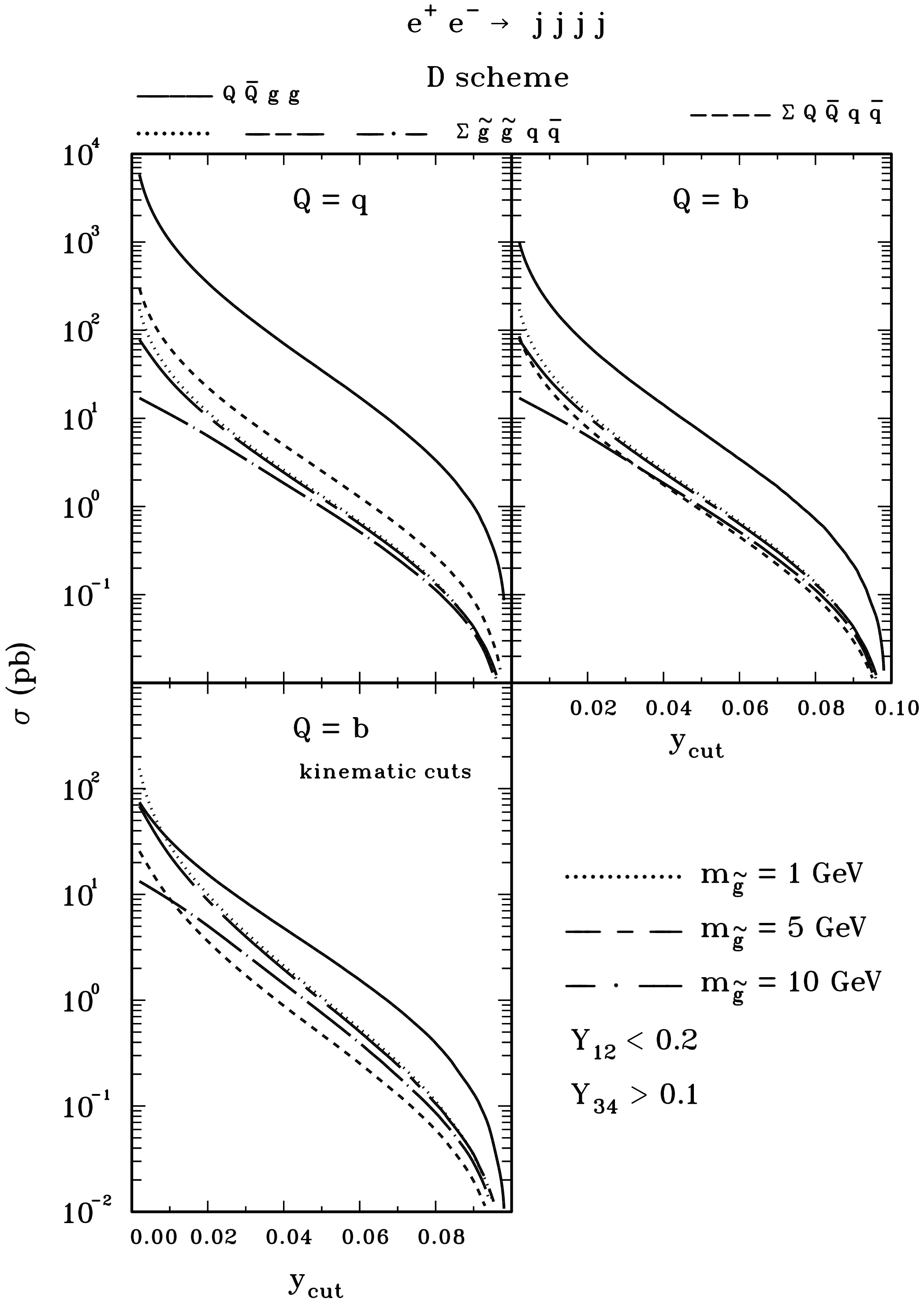

Fig. 2

Total cross sections of ordinary QCD and of SUSY 4-jet events, in the D scheme, without ($Q = q$) and with ($Q = b$) vertex tagging, and after the kinematic cuts, for three different values of $m_{\tilde{g}}$.

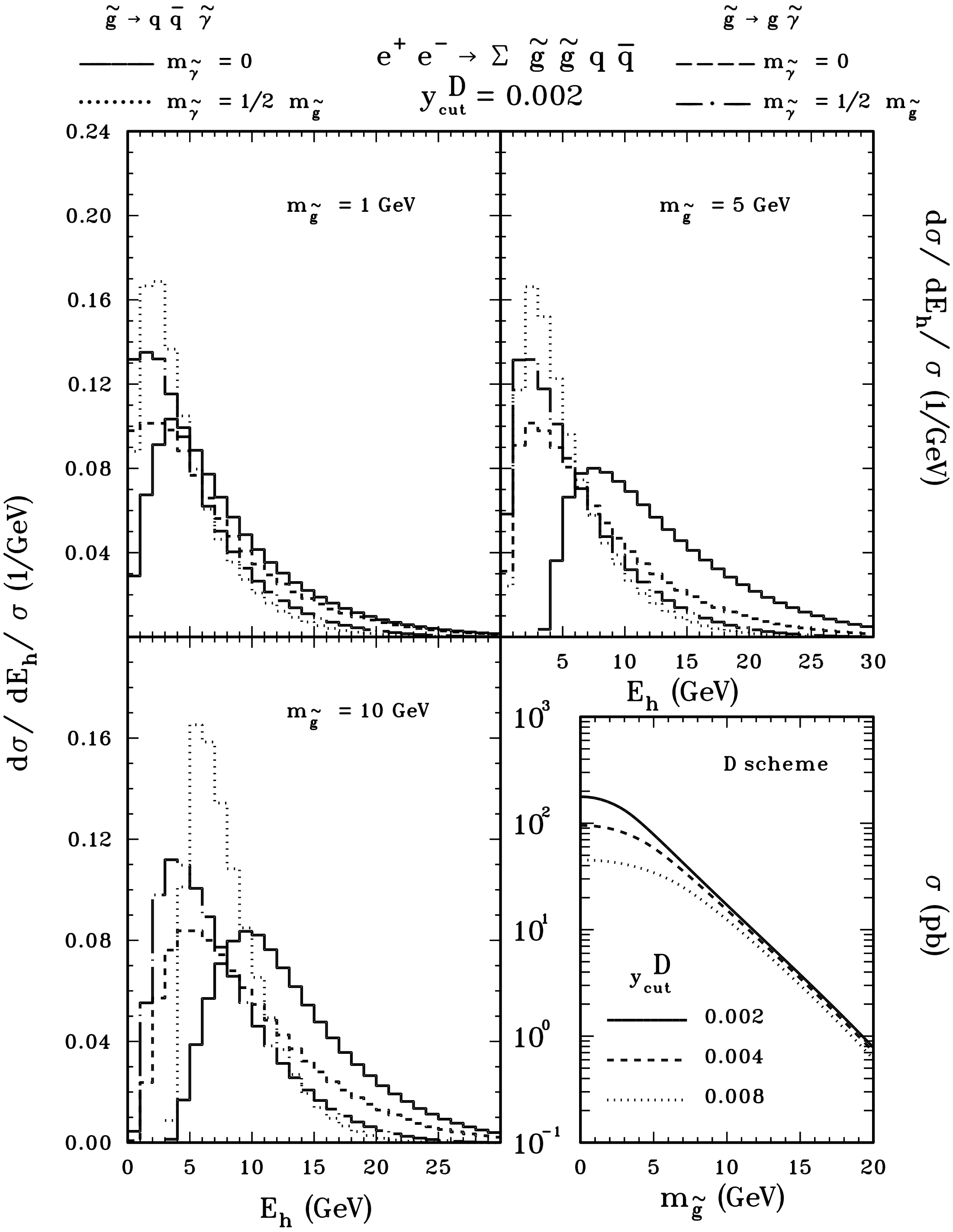

Fig. 3

Differential distributions in the hadronic energy of the 'gluino jet' after the two possible SUSY decays, in the D scheme, for various combinations of $m_{\tilde{g}}$ and $m_{\tilde{\gamma}}$; and total cross section of gluino events in 4-jets, as a function of $m_{\tilde{g}}$ and for three different values of $y^D_{\rm cut}$.