Have Gluinos been Observed at the $p\bar{p}$ Collider?

E. Reya and D. P. Roy[(a)]
Institut für Physik, Universität Dortmund, D-4600 Dortmund 50, West Germany
(Received 14 May 1984)

The recently observed five single-jet events with missing $p_T \geq 35$ GeV can be consistently explained by gluinos ($\tilde{g}$), i.e., the supersymmetric partners of the gluons (g), produced via $q\bar{q} \to \tilde{g}\tilde{g}$ and $gg \to \tilde{g}\tilde{g}$, with a mass in the range $15 \lesssim m_{\tilde{q}} \lesssim 45$ GeV. Reducing the p_T^{miss} cut to the 4σ level further constrains this range to $25 \lesssim m_{\tilde{g}} \lesssim 45$ GeV.

PACS numbers: 14.80.Er, 13.85.Hd

Following several authors,[1] we have recently suggested[2] that gluino production at the $p\bar{p}$ collider leads to large missing-p_T events, which should be detectable with the existing data for a gluino mass $m_{\tilde{g}}$ up to 50 GeV. In the meantime several interesting events with large missing p_T plus hadronic jets have been reported from the $p\bar{p}$ collider by Arnison *et al.*[3] However, their experimental cuts are far more severe than those used in Ref. 2, so that no meaningful comparison is possible between the reported events and the results of this analysis. The purpose of this note is to estimate the gluino contribution to jet-plus-missing-p_T events with the experimental cuts of Ref. 3 and compare the result with the events reported there.

We use the standard quark-antiquark and gluon-gluon fusion mechanisms of gluino pair production,[1,2,4]

$$q\bar{q} \to \tilde{g}\tilde{g}, \quad gg \to \tilde{g}\tilde{g}, \tag{1}$$

each of which decays into a photino $\tilde{\gamma}$ via[5]

$$\tilde{g} \to q\bar{q}\tilde{\gamma}. \tag{2}$$

The production and decay formulas can be found in Ref. 2. As in Ref. 2, we use a fairly large value of the QCD parameter Λ (0.4 GeV) and a broad gluon distribution,[6] which seem to be phenomenologically favored. Varying the input parameters within reasonable bounds would change the cross section, for a given gluino mass, by at most a factor of 2. The missing p_T is obtained by vectorially adding the transverse momenta of the two photinos, while the two pairs of $q\bar{q}$ jets in (2) are combined according to the UA1 jet algorithm[3] to obtain the large-p_T hadronic jets. More precisely, the quark jets emerging within a cone of 1 sr are coalesced into a single jet, and a p_T of 2 GeV is added to each resulting jet to account for the soft-scattering contribution ($\simeq 2$ GeV/sr).[3,7] In counting the number of jets, only those with $p_T \geq 10$ GeV are retained.

Figure 1 shows the cross sections for total and one-jet events with missing $p_T > 15$ GeV (top curves). The effects of requiring a trigger jet of $p_T > 25$ GeV and pseudorapidity $|\eta| < 3$, appropriate for the UA1 experiment, are also shown (middle curves). In each case, the difference between the total result (solid curves) and the one-jet contributions (dashed curves) is dominated by two-jet events up to a gluino mass of 40 GeV, above which three-jet events become comparable. At very low gluino masses of about 5 GeV each $q\bar{q}$ pair emerges as a single jet, so that two-jet events dominate the

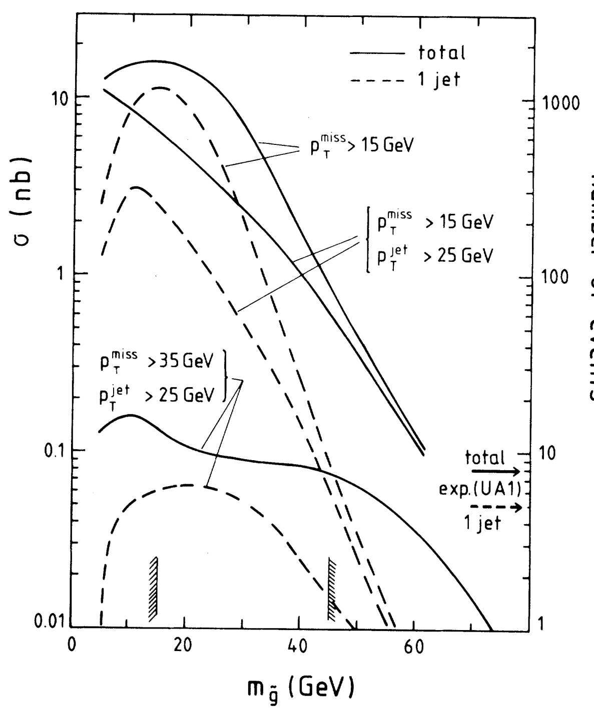

FIG. 1. Predicted cross sections for total and one-jet events originating from the subprocesses in Eq. (1) and the gluino decay in (2) for the $p\bar{p}$ collider energy $\sqrt{s} = 540$ GeV. The indicated experimentally observed "gold plated" events of Ref. 3 correspond to the same cuts as the bottom curves, i.e., $p_T^{\text{miss}} > 35$ GeV and $p_T^{\text{jet}} > 25$ GeV. The allowed gluino mass region lies between the two shaded vertical bars.

total cross section. At an intermediate mass of about 15 GeV the $q\bar{q}$ pairs open into separate jets which are individually soft (mostly $p_T < 10$ GeV) and this results in the dominance of one-jet events. As the gluino mass increases further, however, they become harder because of the larger Q value, and the two-jet events again dominate. The same phenomenon also accounts for a comparatively larger suppression factor due to the triggering requirement ($p_T^{\text{jet}} > 25$ GeV) for intermediate gluino masses. It should be noted, however, that the loss due to the additional triggering requirement is not particularly severe. For an integrated luminosity of 100 events/nb, appropriate for the UA1 experiment, one expects $\geqslant 100$ total events ($\geqslant 10$ one-jet events) with $p_T^{\text{miss}} > 15$ GeV, for a gluino mass of up to 40 GeV. However, the rates are sensitive to the choice of the p_T^{miss} cut, and the present experimental choice is significantly larger than the 15-GeV value used in Ref. 2. The experimental choice of this quantity and its effects on the event rates and distributions are analyzed in detail below.

The experimental cut is[3]

$$p_T^{\text{miss}} > 4\sigma \text{ with } \sigma = 0.7|E_T|^{1/2} \tag{3}$$

in gigaelectronvolt units, and measures the uncertainty in the missing-p_T measurement. Depending on the scalar transverse energy of the event, the p_T^{miss} cut varies over the range 20–35 GeV with a mean value of about 27 GeV. There are five one-jet events[8] (eight total events) above the cut

$$p_T^{\text{miss}} > 35 \text{ GeV}. \tag{4}$$

This cut is particularly clean for two reasons[3]: (i) It holds for the entire range of scalar transverse energy $|E_T|$; (ii) it effectively eliminates the alternative sources of jet plus missing-p_T events. Since these events can *not* be explained by alternative mechanisms,[3,9] they seem particularly suited for a quantitative analysis in terms of gluino production. They are indicated at the bottom of Fig. 1 and compared with the expected number of total and one-jet events for various gluino masses. Allowing for an uncertainty of a factor of 2, one sees that the observed numbers of events[10] are consistent with a gluino mass anywhere in the range

$$15 \lesssim m_{\tilde{g}} \lesssim 45 \text{ GeV}, \tag{5}$$

with an optimal value of about 35 GeV.

We now proceed to cross check this result and to constrain the gluino mass range further by reducing the p_T^{miss} cut to the 4σ level of Eq. (3). A total of 24 events have been observed in this range, of which 16 are one-jet events. These are compared with the model predictions in the above gluino mass range of 15–45 GeV in Table I. Since the present cut depends on E_T we also show the predicted and experimental values of average $|E_T|$. The former are seen to be typically 20% lower than the observed value of $\langle |E_T| \rangle$. Consequently our p_T^{miss} cut is somewhat lower than the experimental one, which results in an overestimation of the number of events. We have checked that the experimental p_T^{miss} cut can be numerically simulated by redefining the model cut as

$$p_T^{\text{miss}} > 4 \times 0.7(|E_T| + \Delta)^{1/2}, \tag{6}$$

where Δ is the difference between the experimental and the theoretical values of $\langle |E_T| \rangle$ for a given gluino mass. The model predictions with this cut are shown in parentheses. Again, allowing for an uncertainty of a factor of 2, we see that the experimental numbers are now consistent with the model prediction over a restricted gluino mass range of 25–45 GeV. The optimal value is again 35 GeV.

We now proceed to check the experimental distributions with our supersymmetric-model predictions for the optimal value of $m_{\tilde{g}} = 35$ GeV. Figure 2(a) compares the p_T^{miss} distribution of the sixteen single-jet events with our model prediction. One finds a good agreement over the whole range $p_T^{\text{miss}} > 4\sigma$. The five "gold plated" events corresponding to $p_T^{\text{miss}} \geqslant 35$ GeV are of course the rightmost ones, having a typical experimental uncertainty of $\Delta p_T^{\text{miss}} = \pm 7$ GeV. Since the experimental p_T^{jet} distribution of these five events is also available we compare it with our prediction in Fig. 2(b). The agreement is again very encouraging.

TABLE I. Predictions for the number of total and one-jet events as well as for the average value of $|E_T|$ with a cut $p_T^{\text{miss}} > 4\sigma$ according to Eq. (3) for the $p\bar{p}$ collider energy $\sqrt{s} = 540$ GeV. The numbers in parentheses are obtained by numerically simulating the experimental 4σ cut according to Eq. (6). The data are taken from Ref. 3.

$M_{\tilde{g}}$ (GeV)	N_{total}	$N_{1-\text{jet}}$	$\langle \lvert E_T \rvert \rangle$ (GeV)
15	162 (71)	107 (49)	68
25	102 (54)	60 (33)	69
35	60 (44)	21 (16)	74
45	27 (25)	6 (5)	81
55	10	1	91
Expt.	24	16	88

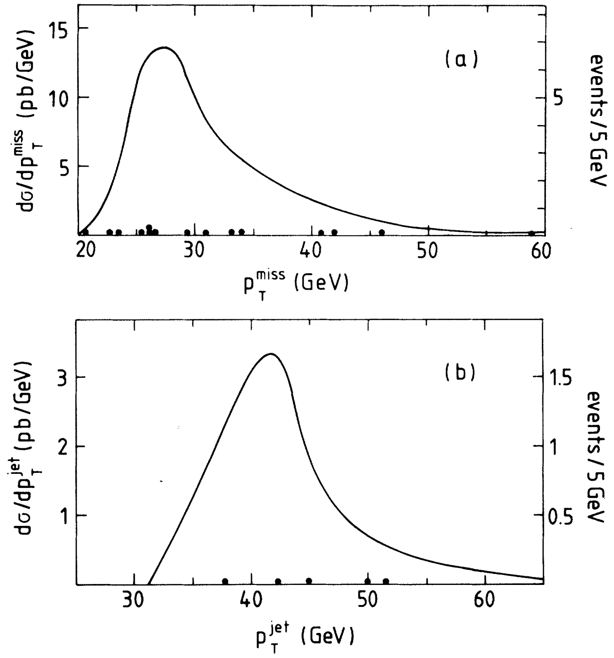

FIG. 2. Predictions for (a) the p_T^{miss} distribution of the sixteen single-jet events and (b) the trigger p_T^{jet} distribution of the five "gold plated" events at $\sqrt{s} = 540$ GeV, with the optimal gluino mass value of $m_{\tilde{g}} = 35$ GeV. The observed events, indicated by the solid dots, are taken from Ref. 3.

Finally, following Ref. 3, we have also computed the number of one-jet events in the interval 15 GeV $< p_T^{miss} < 4\sigma$, satisfying the isolation condition defined there. We find only two additional events from this interval for a gluino mass of 35 GeV. We have also subjected the total sample of eighteen predicted one-jet events to their aplanarity cut[3] $\cos\phi > -0.8$, where ϕ is the azimuth angle between the jet and the remainder $\vec{p}_T$. This does not significantly reduce the number of events with $p_T^{miss} > 35$ GeV, but cuts those below 35 GeV to about eight events. This is evidently consistent with the observation of about fifty events with a QCD background of similar magnitude.[3]

To summarize, we have shown that the five single-jet events with missing transverse energy larger than 35 GeV, recently observed at the CERN $p\bar{p}$ collider, can be consistently explained by the supersymmetric subprocesses $q\bar{q} \rightarrow \tilde{g}\tilde{g}$ and $gg \rightarrow \tilde{g}\tilde{g}$ and the subsequent gluino decay $\tilde{g} \rightarrow q\bar{q}\tilde{\gamma}$ with a gluino mass in the range of $15 \lesssim m_{\tilde{g}} \lesssim 45$ GeV. The optimal value for $m_{\tilde{g}}$ is about 35 GeV. Reducing the p_T^{miss} cut to the 4σ level further constrains the gluino mass to the range of $25 \lesssim m_{\tilde{g}} \lesssim 45$ GeV.

Note added.—In a similar analysis, Ellis and Kowalski[11] obtain a significantly smaller total event rate for a 4σ cut: about ten events for $m_{\tilde{g}} = 10$–40 GeV (their Fig. 4). Experimentally, however, 24 events have been observed (Ref. 3). Thus, contrary to the conclusion attributed to this analysis in Ref. 3, it actually implies that the data of Ref. 3 can *not* rule out low gluino masses down to 10 GeV. However, a subsequent analysis by the same authors[12] yields a total event rate similar to ours. The remaining main difference between these two analyses and ours is the relative one- and two-jet contribution to the total predicted event rate. Here we only wish to emphasize that for low gluino masses ($m_{\tilde{g}} = 5$–10 GeV) one expects the total cross section to be dominated by two-jet events similarly to the case of b-quark production via $gg \rightarrow b\bar{b}$ (Ref. 11); a similar remarks holds for the maximum jet p_T distribution as well.

[a]On sabbatical leave from the Tata Institute of Fundamental Research, Bombay 400 005, India.

[1]G. L. Kane and J. P. Leveille, Phys. Lett. **112B**, 227 (1982); I. Hinchliffe and L. Littenberg, in *Proceedings of the 1982 Division of Particles and Fields Summer Study on Elementary Particle Physics and Future Facilities, Snowmass, Colorado, 1982,* edited by H. R. Gustafson and Frank Paige (Fermilab, Batavia, Illinois,1983), p. 242; S. H. Aronson *et al., ibid.*, p. 505.

[2]E. Reya and D. P. Roy, Phys. Lett. **141B**, 442 (1984).

[3]G. Arnison *et al.* (UA1 Collaboration), Phys. Lett. **139*B***, 115 (1984).

[4]P. R. Harrison and C. H. Llewellyn-Smith, Nucl. Phys. **B213**, 223 (1983), and **B223**, 542(E) (1983).

[5]We are assuming the most widely favored supersymmetric scenario, where gluinos are expected to be the least massive supersymmetric particles apart from the photino. Since the gluino is lighter than the scalar quark, the gg fusion process is dominant and our results are insensitive to the scalar-quark mass which has been taken to be 100 GeV. Further we have neglected the photino mass.

[6]M. Glück, E. Hoffmann, and E. Reya, Z. Phys. C **13**, 119 (1982).

[7]Similarly, the scalar transverse energy $|E_T|$ is obtained by adding a soft contribution of 25 GeV to the scalar sum of the transverse momenta of the four quark jets.

[8]These are the events B–F of Ref. 3. The event A has a large-p_T muon track, and is therefore excluded.

[9]All possible events from W decay (heavy flavors, τ lepton, possible heavy leptons, supersymmetric partners of the W, scalar leptons, etc.) are kinematically restricted (Ref. 3) to $p_T^{miss} < 35$ GeV. Furthermore, a QCD jet produced in association with an invisible $Z^0 \rightarrow \nu\bar{\nu}$ decay and events of the type W+jet are known [G. Arnison *et al.*

(UA1 Collaboration), Phys. Lett. **129B**, 273 (1983), and **134B**, 469 (1984)] to be much softer than the present ones. Finally the heavy flavor production from quark-antiquark and gluon-gluon fusion processes can give $p_T^{miss} > 35$ GeV, but one estimates less than 0.3 event for charm and bottom, and a similar number for a possible top flavor [Ref. 3; D. P. Roy, Z. Phys. C **21**, 333 (1984)]. This is also consistent with the fact that these processes should give a comparable number of charged lepton events with $p_T > 35$ GeV, none of which have been observed (Ref. 3).

[10]There is a geometrical cut of $\pm 20°$ about the vertical plane in the data, which we have not incorporated in our Monte Carlo program. Correcting for this acceptance cut should increase the experimental number of events, but only by a small amount.

[11]J. Ellis and H. Kowalski, CERN Report No. TH.3843-CERN (unpublished).

[12]J. Ellis and H. Kowalski, DESY Report No. DESY-84-05, 1984 (unpublished).