DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 85-011
MAD/PH/230
February 1985

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ISSN 0418-9833

NOTKESTRASSE 85 · 2 HAMBURG 52

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ABSTRACT

Predictions of the squark pair production scenario, proposed to explain monojets observed at the CERN $p\bar{p}$ collider, are extended to multijets with missing p_T. The n-jet cross sections are calculated from lowest-order subprocesses versus squark and gluino masses and compared to new UA1 data. Predictions are made for azimuthal correlations $\Delta\phi$, pseudorapidity correlation $\Delta\eta$, and a jet transverse momentum asymmetry in dijet events and compared with recently observed dijet data.

After the UA1 collaboration reported[1] the observation of monojet events with large missing transverse momentum ($\not{p}_T$) at the CERN $p\bar{p}$ collider, several models[2-6] based on supersymmetry were proposed to explain the data. Supersymmetry naturally leads to events with $\not{p}_T$ since the photino ($\tilde{\gamma}$), which is produced in $\tilde{q}$ or $\tilde{g}$ decays and is supposed to be stable, interacts feebly and is thereby undetected in collider experiments. A common feature of the supersymmetric interpretations is the prediction of $\not{p}_T$ events with multijets at differing rates.[6] The UA1 collaboration has just reported[7] the observation of four dijet and four monojet events with large $\not{p}_T$ (> 40 GeV) from the new run at $\sqrt{s}$ = 630 GeV. Also, a trijet event with large $\not{p}_T$ was found[1] in the previous run at $\sqrt{s}$ = 540 GeV. With rate and future more detailed information from multijet events, it should soon be possible to more closely define the permissible range of sparticle masses that can describe the observed $\not{p}_T$ events. The new data motivates a more detailed study of the predictions of the various supersymmetry scenarios, all of which have a light photino (< 20 GeV).

The three SUSY scenarios advocated in previous studies are:

(A) squark pair production with $\tilde{q} \to q\tilde{\gamma}$ decay: $m(\tilde{g}) > m(\tilde{q}) \sim 40$ GeV;

(B) gluino pair production with $\tilde{g} \to q\bar{q}\tilde{\gamma}$ decay: $m(\tilde{q}) > m(\tilde{g}) \sim 40$ GeV;

(C) single extra-heavy squark production, from[4] $qg \to \tilde{q}\tilde{g}$ or from[5] $q\tilde{g} \to \tilde{q}$ subprocesses, with a light gluino and $\tilde{q} \to q\tilde{\gamma}$ decay; $m(\tilde{q}) \sim 100$ GeV, $m(\tilde{g}) \sim 3$-10 GeV.

In each scenario the missing p_T is ascribed to decay photinos. In C, gluino pair production does not contribute importantly to large $\not{p}_T$ because of soft $\tilde{g}$ fragmentation.[8] Scenario B is disfavored[6] because it gives rather broad monojets and a soft $\not{p}_T$ spectrum, unlike present indications from the data. Scenario C gives the hardest $\not{p}_T$ spectrum, from the Jacobian peak in the two-body heavy squark decay, for which there may be some preference from the observed monjet $\not{p}_T$ spectrum. However, C gives a rather low dijet to monojet ratio[6] of order 1/3. Because of the new indication that dijets may be as plentiful as monojets (the analysis of the 1983 data may have been biased against detection of dijets[7]), we concentrate our attention here on a more detailed examination of scenario A.

As in previous calculations, we assume that the $\tilde{\gamma}$ and $\tilde{g}$ couplings are flavor diagonal and that the squark mass spectrum is approximately mass degenerate for five flavors and two chiralities; squark masses below 22 GeV are excluded by e^+e^- annihilation experiments.[9] We neglect the photino mass in $\tilde{q} \to q\tilde{\gamma}$ decay calculations. Simple grand unification schemes[10] give the mass relation $m_{\tilde{\gamma}}/m_{\tilde{g}} \simeq 8\alpha/[3\alpha_s(m_{\tilde{g}})] \approx 1/7$ in the absence of significant mixing in the neutral gaugino-higgsino sector. A photino mass of this order would affect our analysis only for limited ranges of the $m_{\tilde{q}}$, $m_{\tilde{g}}$ masses of interest. The cross sections are calculated from the order α_s^2 QCD subprocesses $q\bar{q},gg \to \tilde{q}\bar{\tilde{q}},\tilde{g}\tilde{g}$ and $qg \to \tilde{q}\tilde{g}$ following Ref. 6; contributions from gluino decays $\tilde{g} \to \tilde{q}\bar{q},\bar{\tilde{q}}q$ are taken into account. Final states produced by these subprocesses and subsequent $\tilde{q} \to q\tilde{\gamma}$ decays contain two photinos and from two to four quarks, giving missing p_T and up to four jets.

Jets are defined by an algorithm[6] that approximates that of the UA1 collaboration. Quarks with momenta that satisfy $[(\Delta\eta)^2 + (\Delta\phi)^2]^{1/2} < 1$, where $\Delta\eta$ is the pseudorapidity difference and $\Delta\phi$ is the azimuthal angle difference between them, are coalesced in clusters which are identified as jets provided that $p_T(j) = |\sum_i \vec{p}_{Ti}| > 25$ GeV for the leading jet (j_1) and $p_T(j) > 12$ GeV for any remaining jets $(j_2, j_3, \ldots)$.

Figure 1(a) shows cross section predictions at $\sqrt{s} = 630$ GeV, summed over monojet and dijet events with $\not{p}_T > 40$ GeV, assuming $B(\tilde{q} \to q\tilde{\gamma}) = 1$. The results are presented as contours of constant cross section in a plane with axes $m_{\tilde{q}}$ and $m_{\tilde{g}}$. The cross sections are calculated with a K factor of one, and allowance must be made for the possibility of an enhancement factor of order 2. The cross section values at $\sqrt{s} = 540$ GeV can be approximately obtained by multiplying the results in Fig. 1(a) by 0.6.

We can attempt to estimate the cross section from the eight events at $\sqrt{s} = 630$ GeV with $\not{p}_T > 40$ GeV for the analyzed luminosity of $\int L dt = 0.13$ pb^{-1}. Assuming a detection efficiency ε of order 0.5, and a decay branching fraction $B(\tilde{q} \to q\tilde{\gamma}) > 0.7$, whose precise value depends[11] on the lowest wiggsino mass, we obtain

$$\sum_{n=1,2} \sigma(n\text{-jet}) = N/[B^2 \varepsilon \int L dt] \approx 200 \pm 100 \text{ pb} . \qquad (1)$$

From Fig. 1(a), with K = 1, cross sections of this order are obtained for $m_{\tilde{q}} \leq 70$ GeV.

Figure 1(b) gives the predicted dijet to monojet ratio for $\not{p}_T > 40$ GeV. Assuming that the observation of equal numbers of dijets and monojets in the 1984 run implies that $\sigma(2j)/\sigma(1j) < 2$, we infer the bound

$$m_{\tilde{q}} \lesssim 55 \text{ GeV} . \qquad (2)$$

This restriction is independent of a possible K factor.

The predicted trijet event rate for $\not{p}_T > 40$ GeV relative to the sum of monojets and dijets is rather insensitive to $\tilde{q}$ and $\tilde{g}$ masses. For $m_{\tilde{g}} \lesssim 100$ GeV the result is in the range

$$\sigma(3j)/[\sigma(1j) + \sigma(2j)] \approx 0.08 - 0.16 . \qquad (3)$$

The one observed three-jet event[1] with $\not{p}_T \simeq 51$ GeV is consistent with this expectation. Since QCD radiation (incident parton bremsstrahlung, etc.) may add additional jets at the 10% level, the three-jet rate calculated from $\tilde{q}$ and $\tilde{g}$ decays alone is to be regarded as a lower limit only.

Figure 2 shows the predicted $\not{p}_T$ distributions (> 20 GeV) at $\sqrt{s} = 630$ GeV for one-, two-, and three-jet events with the sparticle mass choices $m_{\tilde{q}}, m_{\tilde{g}}$ = (45,70) and (55,70) in GeV units. The distributions obtained at $\sqrt{s} = 540$ GeV are rather similar to these. The arrows along the top of the figure denote the data values of the UA1 events at $\sqrt{s} = 630$ GeV with $\not{p}_T >$ 40 GeV; the 1983 monojet data at $\sqrt{s} = 540$ GeV are denoted by asterisks. We make the following observations about the results:

(i) The n-jet $\not{p}_T$ distributions fall rapidly with increasing $\not{p}_T$ beyond $\not{p}_T = m_{\tilde{q}}$. Two photinos each with Jacobian peaks at $\frac{1}{2}m_{\tilde{q}}$ can easily add up to give $\not{p}_T \simeq m_{\tilde{q}}$, but not much higher $\not{p}_T$.

(ii) The $\not{p}_T$ distributions are consistent with a squark mass of order 45-55 GeV. For squark masses in this range $\sigma(2j)/\sigma(1j) \sim 2$ for $\not{p}_T > 40$ GeV.

(iii) The $\not{p}_T$ distributions are insensitive to the choice of gluino mass, which we have chosen relatively low to have a larger $\sigma(1j) + \sigma(2j)$ cross section.

Comparisons of the predicted $\not{p}_T$ distributions with the present low statistics data are more meaningful for the cumulative cross section, $\sigma(\not{p}_T > p_T)$, integrated over $\not{p}_T > p_T$. Figure 3 shows this comparison. The discrepancy in the two-jet case is due to the fact that no two-jet events have yet been observed with $\not{p}_T$ between 40 and 50 GeV.

Further tests of the squark pair scenario are possible based on correlations in dijet events. Interesting correlation variables are the azimuthal angular differences $\Delta\phi(j_1 j_2)$ and $\Delta\phi(j_1 \not{p}_T)$, the pseudorapidity

difference $\Delta\eta = \eta(j_1) - \eta(j_2)$ and the transverse momentum asymmetry between the two jets,

$$a \equiv p_T(j_2)/p_T(j_1) \quad . \tag{4}$$

Predictions of these correlations are given in Fig. 4, where the values reported for three of the UA1 dijet events are also shown.

The squark pair scenario predicts dijets with the following features:

(i) $|\Delta\phi(j_1 \not{p}_T)| > 120°$ almost always;

(ii) Broad $\Delta\phi(j_1 j_2)$ distribution, about three quarters of events fall between 40° and 140°;

(iii) Preference for small $\Delta\eta$; about half the dijets have $|\Delta\eta| < 1$;

(iv) A momentum asymmetry between the jets that has a broad enhancement near $p_T(j_2)/p_T(j_1) \simeq 0.4$ (and little contribution below 0.2 due to the cuts).

Acknowledgments

We thank H. Baer, H. Haber, G. Kane and M. Mohammadi for discussions. One of us (W.-Y.K.) thanks Fermilab for use of research facilities.

This research was supported in part by the University of Wisconsin Research Committee with funds granted by the Wisconsin Alumni Research Foundation, and in part by the Department of Energy under contracts DE-AC02-76ER00881 and DE-FG02-84ER40173.

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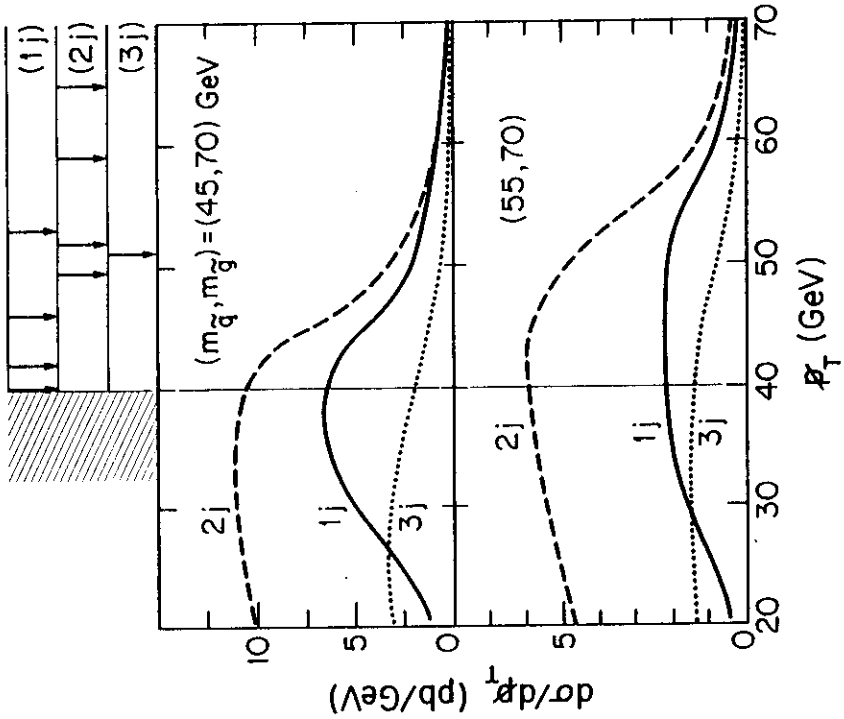
FIGURE CAPTIONS

Fig. 1. Predictions of the squark pair scenario for σ(n-jet) cross sections with $\not{p}_T > 40$ GeV, versus squark and gluino masses (a) $\sigma(1j) + \sigma(2j)$, (b) $\sigma(2j)/\sigma(1j)$. A branching fraction $B(\tilde{q} \to q\tilde{\gamma}) = 1$ is assumed here.

Fig. 2. Predicted $\not{p}_T$ distributions of one-, two- and three-jet events in the squark pair scenario, for the $(m_{\tilde{q}}, m_{\tilde{g}})$ choices (a) (45,70), (b) (55,70) in GeV units. The arrows along the top denote $\not{p}_T$ values of the UA1 events (the asterisks label $\not{p}_T$ values of monojet events from the 1983 run): see Refs. 1, 7.

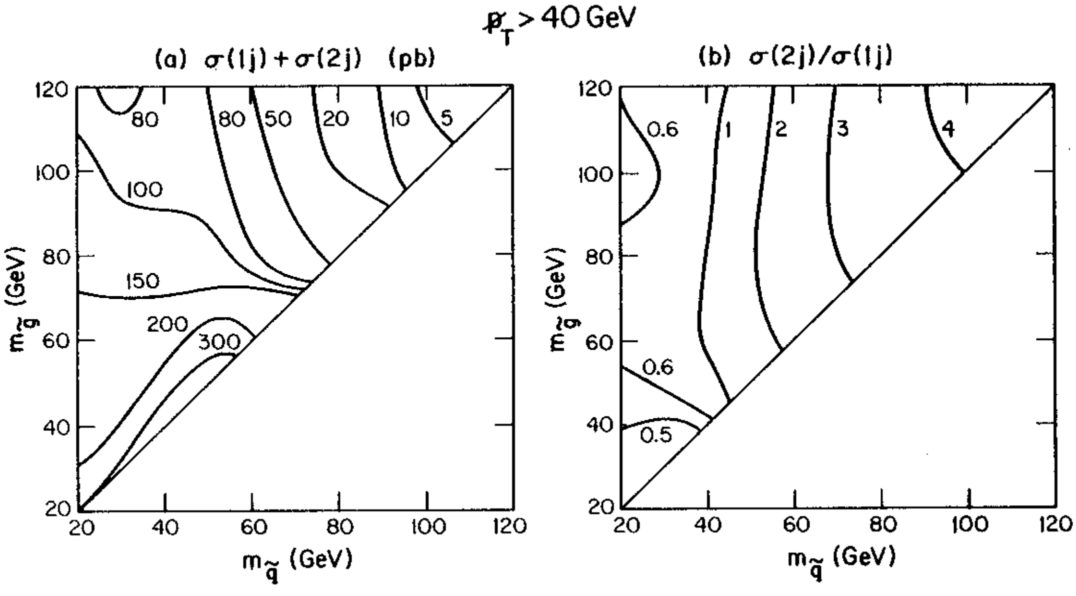
Fig. 3. Cumulative monojet and dijet cross sections with $\not{p}_T > p_T$ for the sparticle mass choices of Fig. 2, compared with the 1984 UA1 data from Ref. 7.

Fig. 4. Predicted correlations in dijet events at $\sqrt{s} = 630$ GeV, compared with UA1 data values from Ref. 7 denoted by the vertical arrows along the top: (a) azimuthal difference between the two jets, $\Delta\phi(j_1, j_2)$, (b) azimuthal difference between the fast jet and the missing p_T, $\Delta\phi(j_1, \not{p}_T)$, and (c) transverse energy asymmetry defined by Eq. (4). The sparticle mass choices $(m_{\tilde{q}}, m_{\tilde{g}})$ = (45,70) and (55,70) GeV are illustrated.



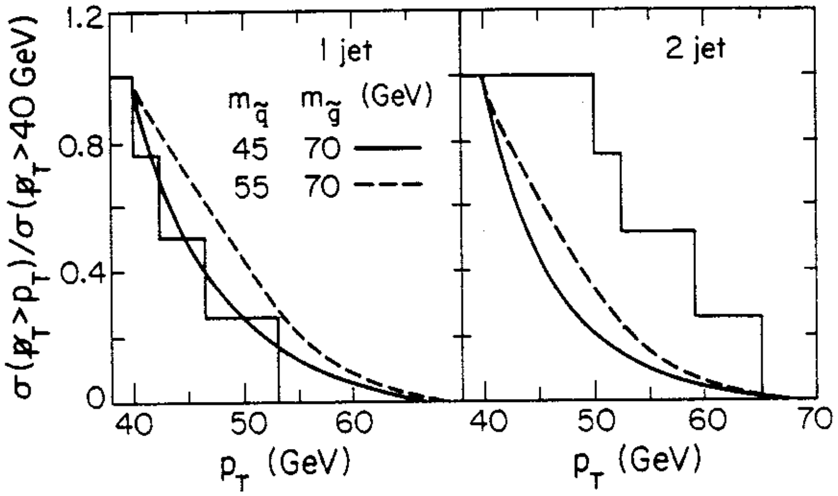
$(m_{\tilde q}, m_{\tilde g}) = (45,70)$ GeV
(55,70)
(1j)
(2j)
(3j)
2j
1j
3j
$d\sigma/d\not p_T$ (pb/GeV)
$\not p_T$ (GeV)

Fig. 2



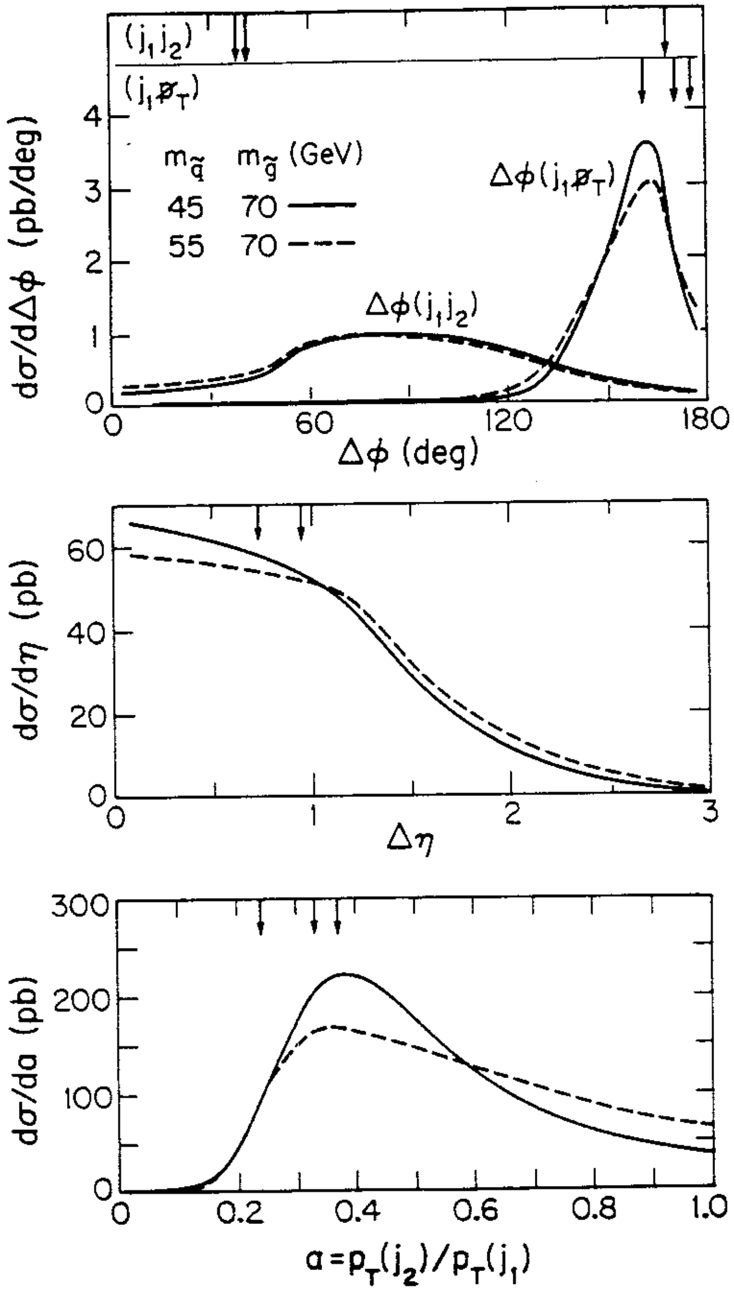
$\not p_T > 40$ GeV
(a) $\sigma(1j) + \sigma(2j)$ (pb)
(b) $\sigma(2j)/\sigma(1j)$
$m_{\tilde g}$ (GeV)
$m_{\tilde q}$ (GeV)

Fig. 1



1 jet
2 jet
$m_{\tilde q}$ $m_{\tilde g}$ (GeV)
45 70
55 70
$\sigma(\not p_T > p_T)/\sigma(\not p_T > 40$ GeV)
p_T (GeV)

Fig. 3



$(j_1 j_2)$
$(j_1 \not p_T)$
$m_{\tilde q}$ $m_{\tilde g}$ (GeV)
45 70
55 70
$\Delta\phi(j_1 \not p_T)$
$\Delta\phi(j_1 j_2)$
$d\sigma/d\Delta\phi$ (pb/deg)
$\Delta\phi$ (deg)
$d\sigma/d\eta$ (pb)
$\Delta\eta$
$d\sigma/da$ (pb)
$a = p_T(j_2)/p_T(j_1)$

Fig. 4