Events with Large Missing Transverse Energy at the CERN Collider :**Search for the Decays of $W^\pm$ into Heavy Leptons and of Z^0 into****Non-Interacting Particles.****(Paper II)***UA1 Collaboration, CERN, Geneva, Switzerland*

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ABSTRACT

We report on further analysis of events with large missing transverse energy from 715 nb^{-1} of data from the UA1 experiment at the CERN proton-antiproton collider. Measured W and Z^0 rates and heavy flavour cross sections are used to predict rates of missing transverse energy events from all known Standard Model processes. Limits are derived on two possible new sources, namely: (1) semi-hadronic decays of a fourth sequential charged heavy lepton coupling to the W boson, and (2) Z^0 decays into additional pairs of non-interacting particles. After taking into account all known sources of missing transverse energy events, we find a mass limit on a fourth generation charged lepton of $m_L > 41 \text{ GeV}/c^2$ (90% C.L.) and a limit on the number of additional neutrino species of $n \leq 7$ (90% C.L.).

1.-Introduction. The analysis of events with large missing transverse energy in proton-antiproton collisions[1] is a powerful method to test the Standard Model and to search for new processes. In a previous paper[2], we have provided the first evidence for the decay $W \rightarrow \tau \nu$, identified primarily by the missing transverse energy and the associated τ hadronic decay modes. The observation of this process is of considerable importance, since (a) it completes the measurement of the expected leptonic decay channels of the W and (b) it demonstrates that the missing transverse energy analysis technique can identify events down to a level $\sim 10^{-9}$ of the total inelastic cross section.

The present paper discusses additional sources of missing transverse energy events. Contributions may arise from known W and Z^0 decays, especially if produced with high transverse momentum, and from heavy flavour decays. New measurements of cross sections at the collider[3,4] now permit a determination of these contributions with adequate precision. A very exciting matter is the possibility of an excess of missing transverse energy events in addition to the above mentioned phenomena.

Direct searches in e^+e^- collisions for a fourth generation charged lepton have placed a mass limit of $22.7 \text{ GeV}/c^2$, at 90% confidence level[5]. The decays of the W provide a previously unexplored mass range in which to search for new leptons[6]. The present UA1 data sample corresponds to the total production of roughly 5600 $W^\pm$ and 2000 Z^0 events, sufficient quantities to allow sensitive searches for new decay modes. We report on a search for a new sequential heavy charged lepton through the processes: $W^- \rightarrow L^- \bar{\nu}$; $L^- \rightarrow \bar{u} d \nu$ or $L^- \rightarrow \bar{c} s \nu$ (or charge conjugate states). The signature is one or two high transverse momentum jets with associated missing transverse energy.

Presently, there exist limits on the number of neutrino families from W and Z^0 data[4], from e^+e^- experiments[7], and from cosmological models[8]. We can use the missing transverse energy events to place a limit on the partial width of the Z^0 decay into non-interacting particles, in particular into new neutrino species, by analysis of the process : $p \bar{p} \rightarrow Z^0 + X$; $Z^0 \rightarrow \bar{\nu} \nu$. Although the Z^0 decay is not detected, the process can produce large missing transverse energy when there are one or more high p_T (gluon) jets recoiling against the Z^0 . The method is similar to

that proposed for e^+e^- collisions[9], where it is planned to count neutrinos by setting the machine energy above the Z^0 resonance and detecting any radiated photon (rather than gluon) from the incoming beam particles.

Supersymmetric particles may also be a source of missing transverse energy, since most models require that the lowest mass particle of the decay chain be stable and non-interacting, thus escaping detection. The production cross section can be reasonably well estimated from a generalisation of QCD and therefore the rate is primarily related to the mass scale of these particles. With the present missing transverse energy data, significant limits can also be set for these processes and will be discussed in a following publication[10].

2.-Data. Data were recorded with the UA1 detector in the period 1983-85 at proton-antiproton centre of mass energies of 546 GeV (118 nb^{-1}) and 630 GeV (597 nb^{-1}). From our missing transverse energy selection[2], we find 56 events containing one or more high transverse energy (E_T) jets with associated isolated missing transverse energy measured with a significance $\geq 4\sigma$. Of the 56 events observed, 53 events have only one jet with $E_T > 12 \text{ GeV}$ (mono-jet events) and 3 events have two jets with $E_T > 12 \text{ GeV}$ (di-jet events). The majority of these events are expected to be $W \rightarrow \tau\nu$, with $\tau \rightarrow \text{hadrons} + \nu$. We have assigned a relative τ -log-likelihood (L_τ) to each event by calculating the relative probabilities for the highest E_T jet in each event to fit the predicted τ properties based on (1) the angular size of the jet, (2) the angular matching of the leading charged particle with the calorimeter jet axis, and (3) the charged particle multiplicity. Figure 1 shows a scatter plot of L_τ vs. the E_T of the largest jet. The 32 events with $L_\tau > 0$ have been reported in ref. [2] and are due mostly to $W \rightarrow \tau\nu$, with $\tau \rightarrow \text{hadrons} + \nu$. In the present paper we discuss the remaining 24 events with $L_\tau < 0$. These are 22 relatively broad mono-jets and 2 di-jet events. An example of a mono-jet event is shown in fig. 2.

3.-Origin of events with $L_\tau < 0$. Since most of the $W \rightarrow \tau\nu$ events are eliminated by the requirement $L_\tau < 0$, the remaining sample has relatively larger contributions from (1) known decays of the W and Z^0 , especially at high transverse momentum, (2) decays of heavy flavours and

(3) fluctuations of detector response to ordinary jets. We have performed extensive Monte Carlo calculations for all known processes which may contribute events with large missing transverse energy. Important features of these calculations are a) simulation of the full proton-antiproton collision to take into account the effects of spectator particles and b) simulation of the UA1 detector including the hardware triggers. Calculations were done using a modified version of the ISAJET Monte Carlo program[11] in which the spectator particle parameters have been adjusted to be consistent with UA1 data. The number of events generated corresponds to approximately 10 times our integrated luminosity.

Because of uncertainties in the normalisation of ISAJET cross-sections for W and Z^0 production, these have been scaled as a function of p_T to agree with experimental data, using our full $W \rightarrow e\nu$ and $W \rightarrow \mu\nu$ samples. Our measured p_T^W spectrum agrees well with perturbative QCD calculations[12] for $p_T^W < 40$ GeV/c. The situation above 40 GeV/c, where only two events are observed, will be discussed in a future publication[13]. For the present analysis, the slope of the ISAJET p_T^W spectrum at 40 GeV/c is used to extrapolate to higher values; we note that the extrapolated spectrum is consistent with the QCD calculations of ref. [12]. Because of limited Z^0 statistics in our data sample (53 events), the ISAJET p_T^Z spectrum has been normalised to maintain the theoretically expected ratio of Z^0/W as a function of p_T .

Processes involving W or Z^0 particles were simulated using a second method where the electron from an identified W decay event is removed and a Monte Carlo decay of a W or Z^0 with the same momentum vector is superimposed on the rest of the event. This method gives agreement with the ISAJET calculations for $p_T^W < 40$ GeV/c within the statistics available from the W and Z^0 samples.

The background due to fluctuations of detector response has been evaluated with a separate Monte Carlo technique, using UA1 jet data as described in ref. [2]. To check the Monte Carlo predictions, we studied the effects of loosening various selection cuts. For example, we have examined the much larger sample of $>3\sigma$ missing transverse energy events, where jet fluctuations have a dominant contribution, and found good agreement between Monte Carlo and data (fig.3).

The contributions to the $>4\sigma$ missing E_T sample from the processes considered are listed in

Table 1. In addition we have calculated the expected contribution of missing transverse energy events from the top quark[14] due to the processes $W \rightarrow t \bar{b}$, $Z^0 \rightarrow \bar{t} t$, and direct $\bar{t} t$. For a top quark mass of $40 \text{ GeV}/c^2$ we expect an additional (2.9 ± 1.5) events, while for a mass of $30 \text{ GeV}/c^2$ the number expected is (4.3 ± 2.2) events. There is clearly room in the data for these small contributions.

The statistical error on the Monte Carlo prediction of 20.8 events with $L_\tau < 0$ is ± 5.1 events. This error includes the statistical errors on the measurement of the high transverse momentum W and Z^0 cross sections (4.6 events) and the statistical errors of the Monte Carlo generation (2.0 events). The systematic error of ± 1.0 events contains the uncertainties in the jet energy scale (0.7 events), in the jet fluctuation background (0.7 events), in the τ acceptance (0.5 events), and in the heavy flavour cross sections (0.2 events).

4.-Results. We observe 24 events with $L_\tau < 0$, compared to $20.8 \pm 5.1 \pm 1.0$ events predicted by the Monte Carlo calculations of known processes (see Table 1). The jet E_T and missing E_T distributions are shown in figs. 4a and 4b, together with the expected contributions. The overall agreement between the data and the Monte Carlo predictions is rather good, apart from a slight excess of events at large values of jet E_T . Although this excess is not statistically significant, we note that the events in this region are expected to come mainly from high p_T W or Z^0 production, in particular $Z^0 \rightarrow \bar{\nu}\nu$. Since the Monte Carlo predictions for $p_T^W > 40 \text{ GeV}/c$ are not directly normalised to experimental data, the corresponding region of $E_T(\text{jet}) > 40 \text{ GeV}$ is sensitive to any anomalous behaviour in the high p_T production of W and Z^0 . Indeed, the two highest missing E_T events ($E_T^{\text{miss}} = 71$ and 63 GeV) each contain two large jets balanced by missing energy, a similar topology to the two highest p_T^W events where two jets are balanced by a W [13]. We will therefore restrict consideration to the well understood region of $E_T(\text{jet}) < 40 \text{ GeV}$ when deriving limits on individual new processes. There are 17 events with $L_\tau < 0$ and $E_T(\text{jet}) < 40 \text{ GeV}$, compared to $17.8 \pm 3.7 \pm 1.0$ predicted by the Monte Carlo calculations.

We can nevertheless derive an inclusive limit, with no cut on $E_T(\text{jet})$, on the total cross section for any new processes producing isolated missing transverse energy events with $L_\tau < 0$.

We stress that this limit is process dependent, being sensitive to the efficiency (ϵ) for passing all the event selection cuts, including the requirement of $L_\tau < 0$. Using the 24 events observed, compared to $20.8 \pm 5.1 \pm 1.0$ predicted, we derive the limit of cross section times efficiency of: $\sigma \epsilon < 20$ pb (90% C.L.). The calculation of the limit takes into account the systematic errors of the Monte Carlo prediction.

The existence of three generations of leptons and quarks is well established, while the possibility of a fourth generation is allowed by the standard model. The weak couplings of a new generation to the W and Z^0 should be of universal strength. This universality has been explicitly tested to about 10% for the leptonic decay modes of the W into electron, muon and tau families[2]. Heavy lepton final states have been fully simulated using ISAJET with the addition of spin effects[15] and full detector simulation. The event rates are predicted from the measured $W \rightarrow e\nu$ rates, including the effects of phase space, trigger acceptance[16] and event selection cuts. The net acceptance for a heavy lepton of mass $40 \text{ GeV}/c^2$, decaying semi-hadronically, is 6.2%, compared to 10.6% for the τ . The expected number of events, as a function of heavy lepton mass (m_L), is shown in Table 2. With the jet definitions used[17], most of the heavy lepton decays are predicted to give monojet events. The number of two jet events ranges from 2.5 for $m_L=25 \text{ GeV}/c^2$ to 0.3 for $m_L=65 \text{ GeV}/c^2$. Figure 5a shows the expected contributions of events with $L_\tau < 0$ for heavy lepton masses of $35 \text{ GeV}/c^2$ and $55 \text{ GeV}/c^2$ respectively, compared with the data (24 events) after the known processes have been subtracted. As discussed earlier, we restrict consideration to the region $L_\tau < 0$ and $E_T(\text{jet}) < 40 \text{ GeV}$ in order to determine a mass limit; this region is in fact preferentially populated by the Monte Carlo heavy lepton events. Using the calculated heavy lepton contributions and taking into account the corresponding additional neutrino coupling to the Z^0 , we derive the limit: $m_L > 41 \text{ GeV}/c^2$ (90% C.L.). In computing this limit, top quark contributions were not added to the background and $L \rightarrow t \bar{b} \bar{\nu}$ decays were not included in the predicted event rates. These contributions, if included, would increase the limit.

Another possible new source of events would be the existence of additional neutrinos coupling to the Z^0 . In the region $E_T(\text{jet}) < 40 \text{ GeV}$ and $L_\tau < 0$, we calculate a contribution of 1.8 events from $Z^0 \rightarrow \bar{\nu}\nu$ for each neutrino species[18]. The net acceptance for detecting a

missing transverse energy event from $Z^0 \rightarrow \bar{\nu}\nu$ decay is 1.8%. Using the 17 events observed, compared to $17.8 \pm 3.7 \pm 1.0$ predicted for the standard processes, we derive the limit on the number of *extra* neutrino species: $n \leq 7$ (90% C.L.). The expected contribution for seven extra neutrino species is shown in fig. 5b. Including contributions from the top quark would decrease the number of extra neutrinos allowed. We may also place an upper limit on the partial width (Γ_P) of the Z^0 into any light neutral non-interacting particles (assuming a partial width of 180 MeV for each decay, appropriate for $Z^0 \rightarrow \bar{\nu}\nu$ decays) of: $\Gamma_P \leq 1.8 \text{ GeV}$ (90% C.L.).

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Table 1. Predicted rates for processes giving large missing transverse energy events passing all event selection cuts.

Process	Events (total)	Events with $L_{\tau} < 0$	Events with $L_{\tau} < 0$ and $E_T^{\text{jet}} < 40 \text{ GeV}$
$W \rightarrow e \nu$ $W \rightarrow \mu \nu$ $W \rightarrow \tau \nu \rightarrow \text{leptons}$	3.6	2.0	1.4
$W \rightarrow \tau \nu$ $\rightarrow \nu \bar{\nu} + \text{hadrons}$	36.7	8.0	7.1
$W \rightarrow c \bar{s}$	<0.1	<0.1	<0.1
$Z^0 \rightarrow \tau^+ \tau^-$	0.5	0.1	0.1
$Z^0 \rightarrow \nu \bar{\nu}$ (3 neutrino species)	7.4	7.1	5.6
$Z^0 \rightarrow c \bar{c} \text{ and } b \bar{b}$	<0.1	<0.1	<0.1
$c \bar{c} \text{ and } b \bar{b}$ (direct production)	0.2	0.2	0.2
Jet fluctuations (fake missing energy)	3.8	3.4	3.4
TOTAL	52.2	$20.8 \pm 5.1 \pm 1.0$	$17.8 \pm 3.7 \pm 1.0$

Table 2. Predicted event rates for the process $W \rightarrow Lv$; $L \rightarrow \bar{q}qv$, passing all event selection cuts, for different heavy lepton masses.

Mass (GeV/c ²)	Total	$L_\tau < 0$	$L_\tau < 0$ $E_T^{\text{jet}} < 40 \text{ GeV}$
25	18.5	17.0	16.0
35	13.6	12.3	11.4
45	8.6	8.0	7.6
55	4.4	3.9	3.9
65	1.8	1.5	1.4

REFERENCES

- [1] G. Arnison *et al.*, Phys. Lett. **139B** (1984) 115.
- [2] C. Albajar *et al.*, UA1 Collaboration, *Events with Large Missing Transverse Energy at the CERN Collider: Observation of $W \rightarrow \tau\nu$ Decay and Tests of τ - μ - e Universality at $Q^2 = m_W^2$ (Paper I)*, CERN-EP/86-81 (1986), submitted to Phys. Lett.
- [3] C. Albajar *et al.*, UA1 Collaboration, *Beauty Production at the CERN Proton-Antiproton Collider. (Paper I)*, paper in preparation.
- [4] G. Arnison *et al.*, Europhys. Lett. **1** (1986) 327; J. A. Appel *et al.*, Z. Phys. C **30**, (1986) 1; D. Denegri (UA1 Collaboration) and S. Loucatos (UA2 Collaboration), to be published in Proceedings of the 6th International Conference on $\bar{p}p$ Physics, Aachen, Germany, 30 June - 4 July, 1986.
- [5] S. Komamiya, in Proc. of the 1985 International Symposium on Lepton Photon Interactions at High Energies, Kyoto.
- [6] D. Cline and C. Rubbia, Phys. Lett. **127B** (1983) 277; V. Barger *et al.*, Phys. Lett. **133B** (1983) 449; V. Barger *et al.*, Phys. Rev. **D29** (1984) 2020.
- [7] S. Whitaker, *Single Photon Searches in e^+e^- (ASP, CELLO, MAC)*, to be published in Proceedings of the XXIII International Conference on High Energy Physics, Berkeley, California, July 1986.
- [8] A. M. Bøsegaard and G. Steigman, Ann. Rev. Astron. Astro. **23** (1985) 315; D. N. Schramm and G. Steigman, Phys. Lett. **141B** (1984) 337; J. Ellis, K. Enqvist, and D. V. Nanopoulos, Phys. Lett. **167B** (1986) 987; G. Steigman *et al.*, Phys. Lett. **176B** (1986) 33.
- [9] G. Barbiellini *et al.*, Phys. Lett. **106B** 414 (1981); E. Simopoulos, Physics at LEP, CERN 86-02, Vol. I, 197.
- [10] C. Albajar *et al.*, UA1 Collaboration, *Events with Large Missing Transverse Energy at the CERN Collider: Mass Limits on Supersymmetric Particles (Paper III)*, paper in preparation.
- [11] F. Paige and S. Protopopescu, ISAJET Program Version 5.20, BNL38034 (1986); F. Paige, private communication.
- [12] F. Halzen, A.D. Martin and D.M. Scott, Physical Review **D25** (1982) 754 ; A. Nakamura, G. Pancheri and Y.N. Srivastava, Phys. Rev. **D29** (1984) 1936; G. Altarelli, R. K. Ellis, M. Greco and G. Martinelli, Nucl. Phys. **B246** (1984) 12; G. Altarelli, R. K. Ellis, and G. Martinelli, Z. Phys. C. **27** (1985) 617.
- [13] C. Albajar *et al.*, UA1 Collaboration, paper in preparation.
- [14] G. Arnison *et al.*, Phys. Lett. **147B** (1984) 493.
- [15] P. Aurenche and R. Kinnunen, Z.Phys.C. **28** (1985) 107; M. Mohammadi, Ph.D. thesis, University of Wisconsin (in preparation).
- [16] The phase space factor, not including the assumed semi-hadronic branching ratio of 2/3, is equal to $(1-3r/2+r^3/2)$, where $r = (m_L/m_W)^2$. The hardware trigger acceptance ranges from 34% at $m_L=25 \text{ GeV}/c^2$ to 54% at $m_L=65 \text{ GeV}/c^2$.

- [17] For a description of the UA1 jet algorithm, see G. Arnison *et al.*, Phys. Lett. **132B** (1983) 214.
- [18] We assume massless neutrinos. The ratio of partial widths $\Gamma_{ee}/\Gamma_{\nu\nu}$ is calculated to be $(1-4s+8s^2)$, where s is the square of the sine of the weak mixing angle Θ_W . For the presently accepted value of $\sin^2\Theta_W = 0.23$, $\Gamma_{ee}/\Gamma_{\nu\nu} = 0.5$. See D. Albert *et al.*, Nucl. Phys. **B166** (1980) 460; W. Marciano and Z. Parsa, Proc. of the 1982 DPF Summer Study on Elementary Particle Physics and Future Facilities, Snowmass (1982) 155.

FIGURE CAPTIONS

- Fig. 1.** Scatter plot of τ -log-likelihood, L_τ , versus the transverse energy of the highest E_T jet in the event for 56 events. The projections for L_τ and $E_T(\text{jet})$ are plotted for the data (histograms), all predicted contributions (solid line) and non- τ contributions (shaded area). The different symbols indicate the charged multiplicity n of the highest E_T jet.
- Fig. 2.** Event display of a mono-jet event in the UA1 detector. Only tracks with $p_T > 1$ GeV/c and calorimeter cells with $E_T > 1$ GeV are displayed.
- Fig. 3.** Distribution of N_σ for $>3\sigma$ mono-jet events (histogram), compared with all expected contributions (solid line), and jet fluctuation contributions only (shaded area). N_σ is defined as $E_T^{\text{miss}} / (0.7\sqrt{\Sigma E_T})$ where ΣE_T is the scalar sum of transverse energy observed in all calorimeter cells and where transverse energies are measured in GeV.
- Fig. 4a.** Jet transverse energy distribution for events passing the cut $L_\tau < 0$ (24 events, histogram) compared with all expected contributions (solid line).
- Fig. 4b.** Missing transverse energy distribution for events passing the cut $L_\tau < 0$ (24 events, histogram) compared with all expected contributions (solid line).
- Fig. 5a.** Jet transverse energy distribution for background-subtracted data passing the cut $L_\tau < 0$ (points with error bars). Also shown are the predicted distributions from a heavy lepton of mass $m_L = 35$ GeV/c² (solid line) and $m_L = 55$ GeV/c² (dashed line).
- Fig. 5b.** Jet transverse energy distribution for background-subtracted data passing the cut $L_\tau < 0$ (points with error bars) compared with the expected contribution from 7 extra neutrino species (solid line).

FIG. 1

FIG. 2

FIG. 3

FIG. 4a

FIG. 4b

FIG. 5a

FIG. 5b