

ASSOCIATED PRODUCTION OF W'S AND Z'S WITH JETS IN UA2

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ABSTRACT

In the 1983 CERN $\bar{p}p$ collider run, at $\sqrt{s} = 546$ GeV and with an integrated luminosity of 126 nb^{-1} , the UA2 collaboration observed 3 events containing a well identified electron produced in association with a large missing transverse momentum and a hard jet or jets. These events were found difficult to be interpreted in terms of QCD W production. The absence of similar new events in the 1984 data sample, despite the increased energy ($\sqrt{s} = 630$ GeV) and the larger integrated luminosity ($\mathcal{L} = 310 \text{ nb}^{-1}$), makes the interpretation of the 1983 data in terms of standard QCD W + jet(s) production much more likely.

In the total data sample, 128 events interpreted as $W \rightarrow e\nu$ decays with missing transverse momentum exceeding 25 GeV/c are observed in low background conditions. Of those, 31 events are associated with a jet of transverse energy exceeding 5 GeV.

Including these events with hard jets, an average $p_{\perp}^W$ of 8.5 ± 0.8 GeV/c is measured.

1. INTRODUCTION

In a previous publication¹⁾ we have reported the observation of events containing an electron-neutrino pair in the final state, from data taken at $\sqrt{s} = 546$ GeV in the UA2 experiment²⁾ at the CERN $p\bar{p}$ collider³⁾ in the period 1982-1983. We have given a detailed analysis of these events in terms of the production and decay of the electroweak bosons $W^\pm$. We have also reported⁴⁾ on 8 events containing an electron pair in the final state, all associated with the production and decay of the electroweak boson Z^0 .

The analysis reported in ref. 1 discarded events for which a significant amount of transverse energy was detected at opposite azimuth to the electron candidate. This procedure efficiently rejected two-jet events in which one of the jets was misidentified as an electron. Other events, however containing a genuine electron in the final state, may have also been rejected by this cut.

The purpose of this contribution is to report on a systematic search for events containing an electron-neutrino pair in the final state, whatever the transverse energy at opposite azimuth to the electron may be. The loss of rejection power against background, resulting from having relaxed this constraint, is compensated by the requirement that both the electron and the neutrino have large transverse momenta. In 1983 three events were found using this method for which the interpretation $\bar{p} + p \rightarrow W + \text{hard jet(s)}, W \rightarrow e\nu$ was found to be unlikely in terms of conventional QCD⁵⁾.

The UA2 detector has been described in detail elsewhere²⁾. Therefore its features will not be repeated here.

2. DATA SAMPLE

2.1 REMINDER OF THE 1983 DATA

The 1983 data use a sample of 225 events containing an electron candidate having $p_{\perp}^e > 15$ GeV/c and obeying the selection criteria described in Table 1 of ref. 1. This event sample corresponds to an integrated luminosity of 142 nb^{-1} . We discard from this sample events collected in the 1982 period, during which the azimuthal coverage of the UA2 detector was incomplete²⁾. We also discard 10 events for which the electron candidate is observed near the interface between the central region and one of the forward regions and is associated with nearby calorimeter energy in both regions. In such cases, when the electron candidate is likely to be a misidentified jet, a significant fraction of the jet energy can be lost in the magnet coils at the interface of the two regions, and possibly simulating a neutrino. Therefore, the initial sample is reduced to 190 events, and the corresponding integrated luminosity to 126 nb^{-1} .

The efficiency to identify an electron with the UA2 selection criteria is estimated¹⁾ to be 80% in the forward regions and 76% in the central region.

In each event we reduce the final state to a set of transverse energy clusters according to simple algorithms which have been described elsewhere [1,2]. One of the clusters is associated with the electron candidate. Each of the other clusters is usually associated with a multiparticle jet provided it carries large transverse energy. For this reason, in what follows, we shall call "jets", clusters having a transverse energy in excess of 3 GeV. This threshold has been increased to 5 GeV for the 1984 data.

For each event we define a total jet transverse energy $E_{\perp}^J$ as the sum of all jet transverse energies $E_{\perp}^j$ assuming each jet cluster to be massless such that

$$E_{\perp}^J = \sum E_{\perp}^j.$$

We also evaluate the vector sum $\vec{p}_{\perp}^{Je}$ from the momentum vectors of all jet clusters, $\vec{p}_{\perp}^j$, and of the electron, $\vec{p}_{\perp}^e$, such that

$$\vec{p}_\perp^{\text{Je}} = \sum \vec{p}_\perp^{\text{j}} + \vec{p}_\perp^{\text{e}}.$$

The quantity $p_\perp^{\text{Je}}$ measures the missing transverse momentum in the set of all detected particles resulting in clusters in excess of $E_\perp > 3$ GeV ($E_\perp > 5$ GeV for 1984). In a typical event, the softer particles carry together only a small transverse momentum and, if no large transverse momentum particle has escaped detection, the observation of a large $p_\perp^{\text{Je}}$ may be interpreted as due to the presence of a neutrino (ν) with $p_\perp^\nu \approx p_\perp^{\text{Je}}$.

The distribution of events in the $p_\perp^\nu, E_\perp^{\text{J}}$ plane is shown in Fig. 1 for the signal and the background samples. The signal sample contains 7 Z^0 events for which the second electron is interpreted as a jet, and 31 events with $p_\perp^\nu > 25$ GeV/c and $E_\perp^{\text{J}} < 30$ GeV, all belonging to the sample of events in ref. 1 where they were interpreted in terms of $W \rightarrow e\nu$ decays. The corresponding distribution for a background sample is shown in Fig. 1b. The transverse momentum distribution of the neutrino is shown in Fig. 2, where a clear Jacobian peak of the neutrino is visible. The background evaluation follows the method described in ref. 1 and measures the probability that a multijet event contains both a misidentified electron and an undetected jet (or jets) escaping the UA2 acceptance. Its distribution is shown as a curve superimposed on the data in Fig. 2. The background contribution amounts to 3.4 ± 0.3 events for $p_\perp^\nu > 25$ GeV/c and to 1.2 ± 0.1 events for $p_\perp^\nu > 30$ GeV/c.

In the kinematic region $p_\perp^\nu > 25$ GeV/c, $E_\perp^{\text{J}} > 30$ GeV we observe 4 events (A, B, C and D) with an expected background contamination of 0.45 ± 0.04 events. It is remarkable that there is no background event in the region $p_\perp^\nu > 50$ GeV/c, $E_\perp^{\text{J}} > 30$ GeV, which contains events A to C. We infer from this a background contamination of at most 0.02 events (90% confidence level) in this region.

In ref. 5 we compare a few characteristic parameters of those 4 events with the sample of $W \rightarrow e\nu$ candidates having $p_\perp^{\text{e}} > 25$ GeV/c to check on the quality of the electron identification. Each of the four events has been examined in detail with the help of a high resolution graphics display facility. The track multiplicity is of course higher here than in most of the $W \rightarrow e\nu$ events studied in ref. 1 and we cannot exclude that the increased complexity of the signal pattern in the central vertex detector could result in some deterioration of the electron identification power.

As far as neutrino identification is concerned, we have checked that in each of the four events there is no sign of large transverse momentum particles having hit passive parts of the UA2 detector, such as the magnet coils, in the azimuthal region where the neutrino is expected. However, in the case of event D which has an azimuthal configuration similar to that of a two-jet event, such an interpretation cannot be completely excluded. In fact event D contains a narrow $e\nu$ pair ($\Delta\phi \approx 17^\circ$) and consists of a large transverse momentum jet ($p_{\perp}^{j1} \approx 70 \text{ GeV}/c$) emitted at opposite azimuth to the electron-neutrino pair and to a smaller transverse momentum jet ($p_{\perp}^{j2} \approx 25 \text{ GeV}/c$). The configuration of this event suggests an interpretation of a semileptonic decay of a heavy flavour particle. However, because of the absence of other events with similar topologies and because of the similarity of its configuration with that of a two-jet event, we prefer to defer such an interpretation until other events of the same kind have been observed. Since we cannot interpret this event as a $W \rightarrow e\nu$ decay it is therefore discarded from further considerations.

The missing transverse momentum (neutrino) might be faked by large transverse momentum particles which escape detection because they are produced at small angles to the beam line. We consider for each event the possibility that a jet having the same transverse momentum as the neutrino candidate be produced at $\theta = 15^\circ$ (or 165°). Under such an assumption we can calculate a lower limit for the invariant mass of the system of all large transverse momentum particles produced in the event, including undetected jet(s) at small angles. In the case of events A to C they correspond to impossible or very unlikely kinematical configurations.

We have also checked the possibility that a muon simulates a neutrino in the UA2 detector. Although we know of no mechanism which could produce a very massive electron-muon pair at a detectable rate, we looked, in each of the three events, for a track in the vertex detector near the neutrino azimuth and associated with calorimeter energy consistent with the response to a minimum ionizing particle. We found none.

In each of the 3 events A, B and C the sharing of the jet energies between the various calorimeter compartments²⁾ is consistent with expectation. Moreover, each jet contains several tracks having their origin at the event

vertex. These observations exclude interpretations in terms of a cosmic ray or beam-gas background.

From this study we conclude for the 1983 data

1. that events A, B, C contain a well identified electron - like the ones observed in $W \rightarrow e\nu$ events with $p_1^e > 25 \text{ GeV}/c$,
2. that the estimated background from fake electrons for these events is very low (< 0.02 events at 90% C.L.),
3. that we have to assign these events to $W \rightarrow e\nu$ decays, if we do not want to invoke new physics. However, their interpretation as $\bar{p}p \rightarrow W + \text{jet(s)}$ events from conventional sources is very unlikely⁵⁾.

2.2 THE 1984 DATA SAMPLE

In the 1984 run the $\bar{p}p$ Collider operated at a higher energy $\sqrt{s} = 630 \text{ GeV}$. The total integrated luminosity accumulated by the UA2 experiment during this run corresponds to 310 nb^{-1} . We therefore expect at least 2.5 times more events like events A, B and C.

In order to reduce the amount of data to be processed for the preliminary analysis presented at this conference, a fast software filter has been applied to the total event sample of "W triggers"⁶⁾. We require an electron-like energy deposition in the calorimeters (i.e. the cluster should have a small energy leakage into the hadronic compartment and small lateral dimensions). The transverse energy of the cluster observed in the electromagnetic calorimeter was required to exceed $15 \text{ GeV}/c$, and the transverse momentum imbalance in the event (p_1^v) had to exceed $13 \text{ GeV}/c$.

After applying the same electron selection criteria as for the 1983 data sample we are left with 250 events with $p_1^e > 17 \text{ GeV}/c$ (the threshold has been increased to eliminate biases due to the filter cuts). The distribution of the events in the p_1^v, E_1^J plane is shown in Fig. 3 for both the signal and the

background samples. The threshold of 5 GeV, which is used to define a jet, is indicated, as well as the threshold of the software trigger bias for $p_{\perp}^{\nu} < 13$ GeV/c. The sample is unbiased at large $p_{\perp}^{\nu}$.

Due to the software trigger threshold ($p_{\perp}^{\nu} > 13$ GeV/c) only 2 of the 8 Z^0 events remain in this sample. In the region $p_{\perp}^{\nu} > 25$ GeV/c and $E_{\perp}^J < 30$ GeV, 94 events are found, most of them interpreted as genuine $W \rightarrow e\nu$ decays (see ref. 6). In the region $p_{\perp}^{\nu} > 25$ GeV/c, $E_{\perp}^J > 30$ GeV, 4 events are found, indicated as events E, F, G and D', but there are no events in the kinematical region of events A, B and C of the 1983 data sample. These events are also indicated in Fig. 3a.

The transverse momentum distribution of the neutrino for all 98 events with $p_{\perp}^{\nu}$ above 25 GeV/c is shown in Fig. 4 together with the background curve. The effect of the software filter cut $p_{\perp}^{\nu} > 13$ GeV is clearly apparent. The background contribution amounts to 11.0 ± 1.4 events for $p_{\perp}^{\nu} > 23$ GeV/c and to 5.8 ± 1.1 events for $p_{\perp}^{\nu} > 30$ GeV/c.

While the three events (E to G) have topological configurations similar to those of events A to C (i.e. the $e\nu$ pair has a large azimuthal separation ($\Delta\phi > 120^\circ$) and is balanced by a jet), event D' contains a very narrow $e\nu$ pair ($\Delta\phi \approx 5^\circ$). It consists of a large transverse momentum jet ($p_{\perp}^{j1} \approx 89$ GeV/c) emitted at opposite azimuth to a less energetic electron ($p_{\perp}^e \approx 56$ GeV/c), thus producing the missing transverse momentum. Its configuration is therefore very different from that of event D. It should be pointed out that the jet might contain an energetic electron, in this case the jet energy would have been overestimated. Since we cannot interpret this event as a $W \rightarrow e\nu$ decay we do not consider it further.

Despite the higher energy and the larger integrated luminosity, we did not observe more events like events A, B and C. Since the detector performance and the selection criteria have not changed between 1983 and 1984, we conclude that the interpretation of the 1983 events in terms of conventional $W + \text{jet(s)}$ production becomes much more likely.

3. EVENT INTERPRETATION

In both this and the following sections we restrict the analysis to the sample of events having a missing transverse momentum in excess of 25 GeV/c; these are therefore likely to contain a large transverse momentum neutrino. With this cut 128 events are left in the combined 1983 and 1984 data sample. We now study whether the configuration and production rate of events A to G are compatible with standard mechanisms of $W \rightarrow e\nu$ production.

Under the assumption that events A to G contain a genuine $e\nu$ pair we calculate for each event its transverse mass $m_1(e\nu)$ and compare it to those of the remaining 122 $W \rightarrow e\nu$ events. The distribution of $m_1(e\nu)$ is shown in Fig. 5, where events A to G are shaded. The Jacobian-like behaviour of the transverse mass distribution with a fall off close to the W mass, suggests an interpretation in terms of a $W \rightarrow e\nu$ decay, the W boson being the only known particle with a large enough mass.

It is indeed possible to adjust the unknown value of $p_{\perp}^{\nu}$ to obtain $m(e\nu) = m(W)$ and to describe the events in terms of associated $W + \text{jet(s)}$ production. There are in general two solutions to this problem, associated with different values of $p_{\perp}^{WJ} \equiv x_F^{WJ} \sqrt{s}/2$ and of $m(WJ)$. Table 1 lists the solution giving the smaller value of $|x_F^{WJ}|$. While events A, B and C populated the region $160 \leq m(WJ) \leq 190 \text{ GeV}/c^2$, which might have suggested an interpretation in terms of a heavy object decaying into a W boson and a hadronic system J, the 1984 events E to G do not cluster in any mass region.

A reasonable upper limit to the rate of occurrence of events containing a $W \rightarrow e\nu$ produced via known processes in association with large transverse momentum jets can be obtained from the relation

$$\frac{\sigma(p\bar{p} \rightarrow W + J + \dots)}{\sigma(p\bar{p} \rightarrow W + \dots)} \leq \frac{\sigma(p\bar{p} \rightarrow j_1 j_2 + J + \dots)}{\sigma(p\bar{p} \rightarrow j_1 j_2 + \dots)}$$

where $j_1 j_2$ is a pair of jets having the same configuration as the $e\nu$ pair ascribed to a W decay. This relation holds approximately for processes in which $j_1 j_2$ couples via a gluon to a quark-antiquark pair. The contribution of other QCD subprocesses, and interferences among them, increases the right hand side of the above relation by only about 30% ⁷⁾.

From a sample of two-jet events recorded by UA2 in 1984 we calculate two ratios, $R_{j_3}^{\text{jet}}$ and R_J^{jet} , which describe two limits of rates of occurrence. The following definitions for the cross-sections are used: σ_0^{jet} represents the cross-section for the reaction $(p\bar{p} \rightarrow j_1 j_2 + \text{anything})$, σ_1 the cross-section for the reaction $(p\bar{p} \rightarrow j_1 j_2 + j_3 + \text{anything})$, and σ_2 the cross-section for the reaction $(p\bar{p} \rightarrow j_1 j_2 + J + \text{anything})$. j_3 is the jet with the highest transverse energy apart from j_1 and j_2 , and J is the sum of all jets in the event. The ratio $R_{j_3}^{\text{jet}}$

$$R_{j_3}^{\text{jet}} = \frac{\int_{E_1^{j_3}}^{\infty} \frac{\partial \sigma_1}{\partial E_1^{j_3}} dE_1^{j_3}}{\sigma_0^{\text{jet}}}$$

is then defined as the number of $(j_1 j_2 + j_3)$ events with the transverse energy of the third jet exceeding a threshold $E_1^{j_3}$ divided by the total number of $(j_1 j_2)$ events. Similarly, the ratio R_J^{jet}

$$R_J^{\text{jet}} = \frac{\int_{E_1^J}^{\infty} \frac{\partial \sigma_2}{\partial E_1^J} dE_1^J}{\sigma_0^{\text{jet}}}$$

is defined as the number of $(j_1 j_2 + J)$ events with the sum E_1^J for all additional jets exceeding a threshold E_1^J , divided by the total number of $(j_1 j_2)$ events.

In Fig. 6a the ratio $R_{j_3}^{\text{jet}}$ of the two-jet data⁸⁾ from the 1984 run at $\sqrt{s} = 630$ GeV is shown as a function of the threshold energy $E_1^{j_3}$. Also shown is the result of a leading order QCD calculation by Kunszt and Pietarinen⁹⁾. In addition to the statistical error, there is a systematic uncertainty of $\sim 45\%$ which results from calibration uncertainties and from jet algorithm errors. The agreement between data and theory is remarkably good.

Similar to the ratios $R_{j_3}^{\text{jet}}$ and R_J^{jet} we define the ratio R_J^W for the W sample with the following definitions for the cross-sections: σ_0^W represents the cross-section for the reaction ($p\bar{p} \rightarrow e\nu + \text{anything}$) and σ_3 the cross-section for the reaction ($p\bar{p} \rightarrow e\nu + J + \text{anything}$)

$$R_J^W = \frac{\int_{E_1^J}^{\infty} \frac{\partial \sigma_3}{\partial E_1^J} dE_1^J}{\sigma_0^W}$$

R_J^W is defined as the number of W + jet(s) events for which the sum E_1^J for all additional jets exceeds a threshold E_1^J , divided by the total number of W events. In Fig. 6b this ratio R_J^W is shown for the 128 W events (including events A to G) as a function of E_1^J . In addition we show the two limits (R_{j_3} and R_J) from the two-jet data as a hatched band. A comparison of the two data samples suggests already that all the W events including events A to G might originate from known QCD processes. We note that the last two data points of R_J^W contain only 2 events (events B and C). It should be pointed out that 30% of the W sample were collected at a lower energy ($\sqrt{s} = 546$ GeV), whereas the two-jet sample used for comparison was collected at a higher energy ($\sqrt{s} = 630$ GeV). This difference in energy results in an increase of the ratio $R_{j_3}^{\text{jet}}$ by a factor of 1.6 to 2.3 for $E_1^{j_3}$ ranges between 40 GeV and 70 GeV.

We evaluate now the two limits for the expected number of events in the configuration of events A to G from the sample of two-jet events using the ratios R_{j_3} and R_J respectively, at the value $E_1^{j_3}$ and E_1^J measured in the events themselves. We take as j (or J) any jet (or system of jets) having a transverse energy at least as large as that of the corresponding jet (or system of jets) in events A, B and E to G. For event C which contains two hard jets, we calculate the lower limit under the condition that the invariant mass of the jet pair be at least as large as the invariant mass of the jet pair of event C.

The results, listed in Table 2, take into account the different acceptances of the UA2 apparatus to $e\nu$ pairs and to jet pairs. The uncertainties quoted in Table 2 account for measurement errors on energies and

angles. The neutrino transverse momentum may be evaluated from the large transverse momentum particles alone, $\bar{p}_1^\nu = -\bar{p}_1^{\text{Je}}$, or by including all other softer particles which do not result in transverse energy clusters exceeding 5 GeV. The differences between the two evaluations are small and have been accounted for in Table 2.

We note that if the $e\nu$ pair in events A to G were coupled to the initial state via a real or virtual W , as expected in standard theories, other events in which the $e\nu$ pair is replaced by a jet pair should also occur, at a rate at least 6 times as high (for the two light quark families). However, this factor is reduced by acceptance effects. A search for such events is beyond the scope of the present paper. Given the small statistics for $W + \text{jet(s)}$ events, a comparison of the expected number of events from the two-jet sample and the observed number of $W + \text{jet(s)}$ events (table 2) suggests that events A to G may well be compatible with QCD expectations.

Also shown in Fig. 6b is a QCD calculation which takes into account corrections up to second order in $\alpha_s^{(10)}$. This calculation does not include yet the correct detector acceptance, or fragmentation effects. We expect that their inclusion will result in a $\sim 50\%$ decrease of R_J^W as indicated by the arrow in Fig. 6b.

In Fig. 6c the ratio of R_J^W is shown separately for the 1983 and the 1984 W samples, together with the behaviour of R_{j_3} and R_J from the two-jet sample. From this figure it is clear that the 1983 data alone suggest a different conclusion.

4. COMPARISON OF THE W AND Z SAMPLES

The W transverse momentum $p_{\perp}^W$ can be evaluated from the momenta of all other particles or jets of particles observed in the event in addition to the electron candidate such that

$$\bar{p}_{\perp}^W = -(\sum \bar{p}_{\perp}^{\text{jet}} + \xi \bar{p}_{\perp}^{\text{sp}})$$

where the sum extends over all observed jets, $p_{\perp}^{\text{sp}}$ is the total transverse momentum carried by the system of all other particles (spectators) not belonging to jets, and ξ is a correction factor which takes into account the non linear response of the calorimeter at low energies (less than about 2 GeV) and the incomplete detection of the rest of the event ($\xi = 1$ for an ideal detector). To determine this correction, we used the 8 Z^0 events from the 1983 data and we compared the mean value of $p_{\perp}^{Z^0}$, which is directly determined from the transverse momenta of the decay products, with $p_{\perp}^{Z^0}$ obtained from the rest of the event using the above equation. Requiring $\langle p_{\perp}^{Z^0} \rangle = \langle p_{\perp}^{Z^0} \rangle$ we find $\xi = 2.2 \pm 0.5$. Using this result we get a corrected distribution of $p_{\perp}^W$ which is shown in Fig. 7 for the full sample of 135 $W \rightarrow e\nu$ events with $p_{\perp}^{\nu} > 25$ GeV/c. For the mean value of $p_{\perp}^W$ we find $\langle p_{\perp}^W \rangle = 8.5 \pm 0.8$ GeV/c, including events A to G which contribute to the highest $p_{\perp}^W$ values. Excluding those events we get a mean value of $\langle p_{\perp}^W \rangle = 6.8 \pm 0.4$ GeV/c. A QCD prediction¹¹⁾ also shown in Fig. 7, for which the $\sqrt{s}$ dependence has been ignored, is consistent with the observed distribution. For $p_{\perp}^W$ above 26 GeV we observe 8 events whereas the theory predicts 4.2 events.

The inset of Fig. 7 shows the distribution of the transverse momentum of the Z^0 , $p_{\perp}^{Z^0}$, with a mean value of $\langle p_{\perp}^{Z^0} \rangle = 5.8 \pm 1.0$ GeV/c. There is good agreement with QCD expectations¹¹⁾.

In Fig. 8 various distributions for the W and the Z^0 sample are shown. Fig. 8a shows, for the W sample, the multiplicity distribution of associated jets. Fig. 8b shows the equivalent distribution for the Z^0 sample. It is expected that the probability of observing a W in association with n jets is proportional to α_s^n , thus leading to an exponential fall-off of the multiplicity distribution. This is evident in Fig. 8a. Fig. 8c shows the transverse energy distribution of 39 jets from the 31 W events with jets, and

Fig. 8d those of 2 jets from the 2 Z^0 events with jets. Most of the events cluster close to 5 GeV, the threshold for the jet definition. Figs. 8e and f show the distribution of $m(WJ)$, the total mass of the W and jet system, for the 31 W events and the 2 Z^0 events containing a jet respectively. We are at present in the process of comparing the distributions of Fig. 8 with theoretical calculations¹⁰⁾.

5. CONCLUSIONS

A search for events containing an electron-neutrino pair satisfying $p_{\perp}^e > 17$ GeV/c and $p_{\perp}^{\nu} > 25$ GeV/c has resulted in 128 events in a combined sample from 1983 and 1984, which have been interpreted in terms of $W^{\pm}$ production, with characteristic properties in agreement with QCD predictions.

We have found 31 events, for which the $e\nu$ pair is produced in association with a jet, or a system of jets, with its transverse energy exceeding 5 GeV. These events have been interpreted in terms of associated production of $W + \text{jet(s)}$.

The 1983 data had given hope for a sign of new physics beyond the Standard Model (events B and C). The 1984 data do not add new events in the kinematical region of events B and C despite the fact that the integrated luminosity has increased by a factor of 2.5. Therefore the interpretation of events A to G in terms of new physics has become less likely.

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FIGURE CAPTIONS

1. a) Distribution of the 190 events of the 1983 data sample in the p_1^v, E_1^J plane. Seven Z^0 events are circled (the eighth one was collected during the 1982 period, see ref. 4. The W region is indicated.
b) Distribution of the background sample in the p_1^v, E_1^J plane. A reduction factor of 141 must be applied to infer from this sample the background contamination to the sample of Fig. 1a.
Lines of constant $p_1^v = 25$ and 50 GeV/c , $E_1^J = 30 \text{ GeV}$ are indicated.
 2. Missing transverse momentum (p_1^v) distribution of the system of jets and electron in the 1983 sample of 190 events. The events with $p_1^v > 25 \text{ GeV/c}$ are shaded.
The solid line corresponds to the calculated background contamination. The four events having $p_1^v > 25 \text{ GeV/c}$, $E_1^J > 30 \text{ GeV}$, are cross-hatched.
 3. a) Distribution of the 250 events of the 1984 data sample in the p_1^v, E_1^J plane. The two Z^0 events are circled (six of eight were cut by the software trigger threshold $p_1^v > 13 \text{ GeV/c}$). The W region is indicated.
b) Distribution of the background sample in the p_1^v, E_1^J plane. A reduction factor of 36 must be applied to infer from this sample the background contamination to the sample of Fig. 3a.
Lines of constant $p_1^v = 25$ and 50 GeV/c , $E_1^J = 30 \text{ GeV}$ are indicated.
 4. b) Missing transverse momentum (p_1^v) distribution of the system of jets and electron in the 1984 sample of 250 events. The events with $p_1^v > 25 \text{ GeV/c}$ are shaded.
The solid line corresponds to the calculated background contamination.
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5. The transverse mass distribution $m_1(\text{ev})$ for the 128 events with $p_1^v > 25 \text{ GeV}/c$. The 6 events A to G are cross-hatched.

6. a) The ratio R_{j_3} of $(j_1 j_2 + j_3)$ events to $(j_1 j_2)$ events, for which the transverse energy of the third jet exceeds E_1^J , as a function of $E_1^{j_3}$.

The solid line corresponds to a QCD calculation of Kunszt and Pietarinen⁹⁾.

b) The ratio R_J^W of $W + \text{jet(s)}$ events to the W events with the transverse energy of the jet or system of jets E_1^J exceeds a threshold E_1^J , as a function of E_1^J . In addition $R_{j_3}^{\text{jet}}$ and R_J^{jet} from the 1984 two-jet sample as a function of $E_1^{j_3}$ and E_1^J respectively is shown as the hatched band. A QCD calculation for the $W + n \text{ jet(s)}$ production, $0 \leq n \leq 2$, from S.D. Ellis, R. Kleiss and W.J. Stirling¹⁰⁾ is shown. The arrow indicates the estimated drop for the correct detector acceptance and fragmentation of the partons taking into account.

c) The ratio R_J^W plotted separately for the 1983 and the 1984 data sample. Superimposed is the ratio R_{j_3} and R_J from the 1984 two jet data sample indicated by the hatched band.

7. The transverse momentum distribution p_1^W of the 128 W events (a correction factor of $\xi = 2.2$ is taken into account for incomplete detector coverage). The events with a jet or system of jets with the transverse energy exceeding 5 GeV are shaded, the events A to G are cross-hatched.

The inset shows the transverse momentum distribution of the Z^0 .

8. a) The multiplicity distribution of $W + n \text{ jets(s)}$, $0 \leq n \leq 3$.

b) Same as 8a for $Z^0 + n \text{ jets(s)}$, $0 \leq n \leq 2$.

c) The transverse energy distribution of the jet. For the events with more than one jet each jet is entered the plot.

d) Same as 8c for the Z^0 sample.

e) Distribution of the mass of the (WJ) system. The events from the 1983 data sample are hatched.

f) Same as 8e for mass of the $(Z^0 J)$ system.

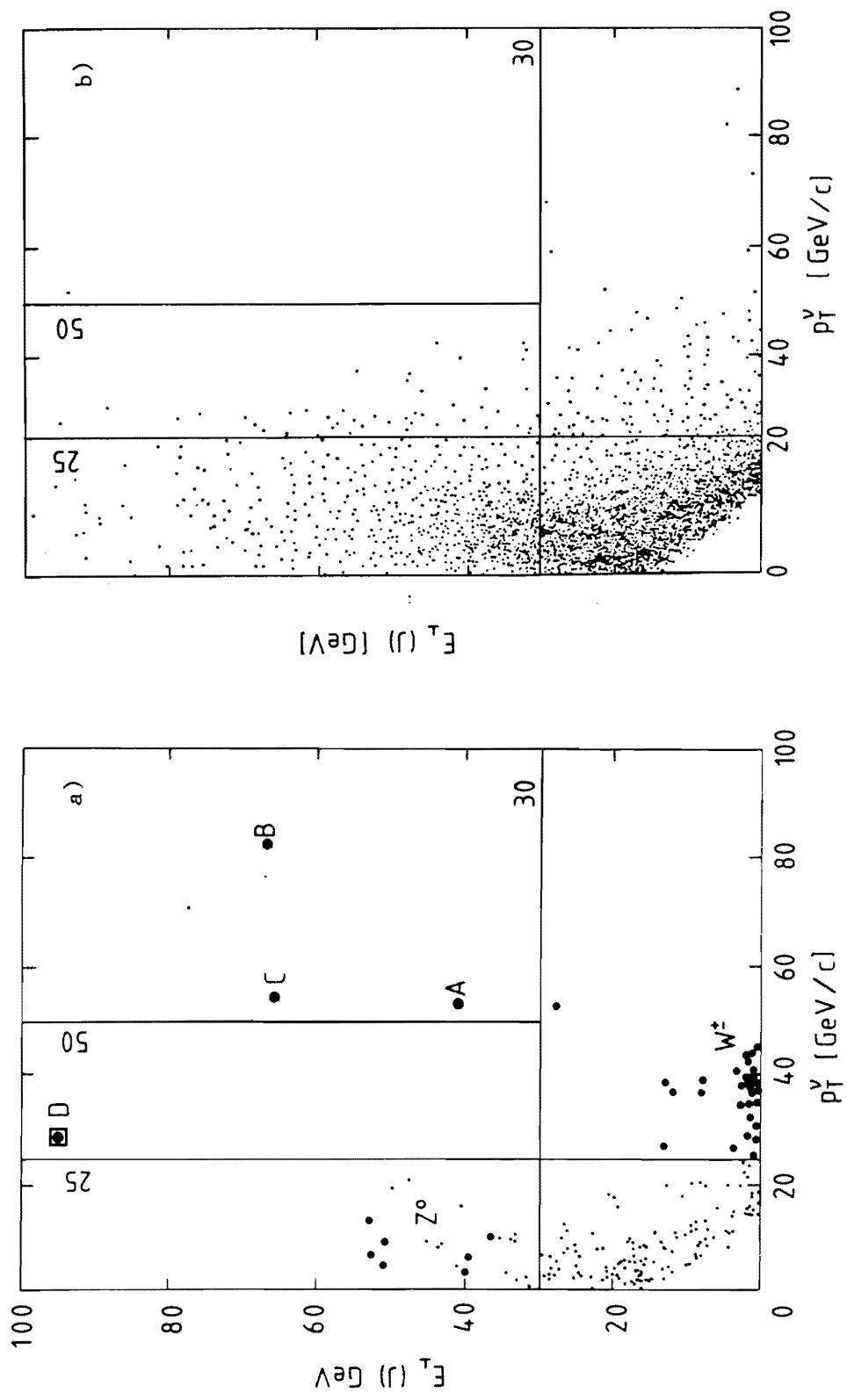


Fig. 1

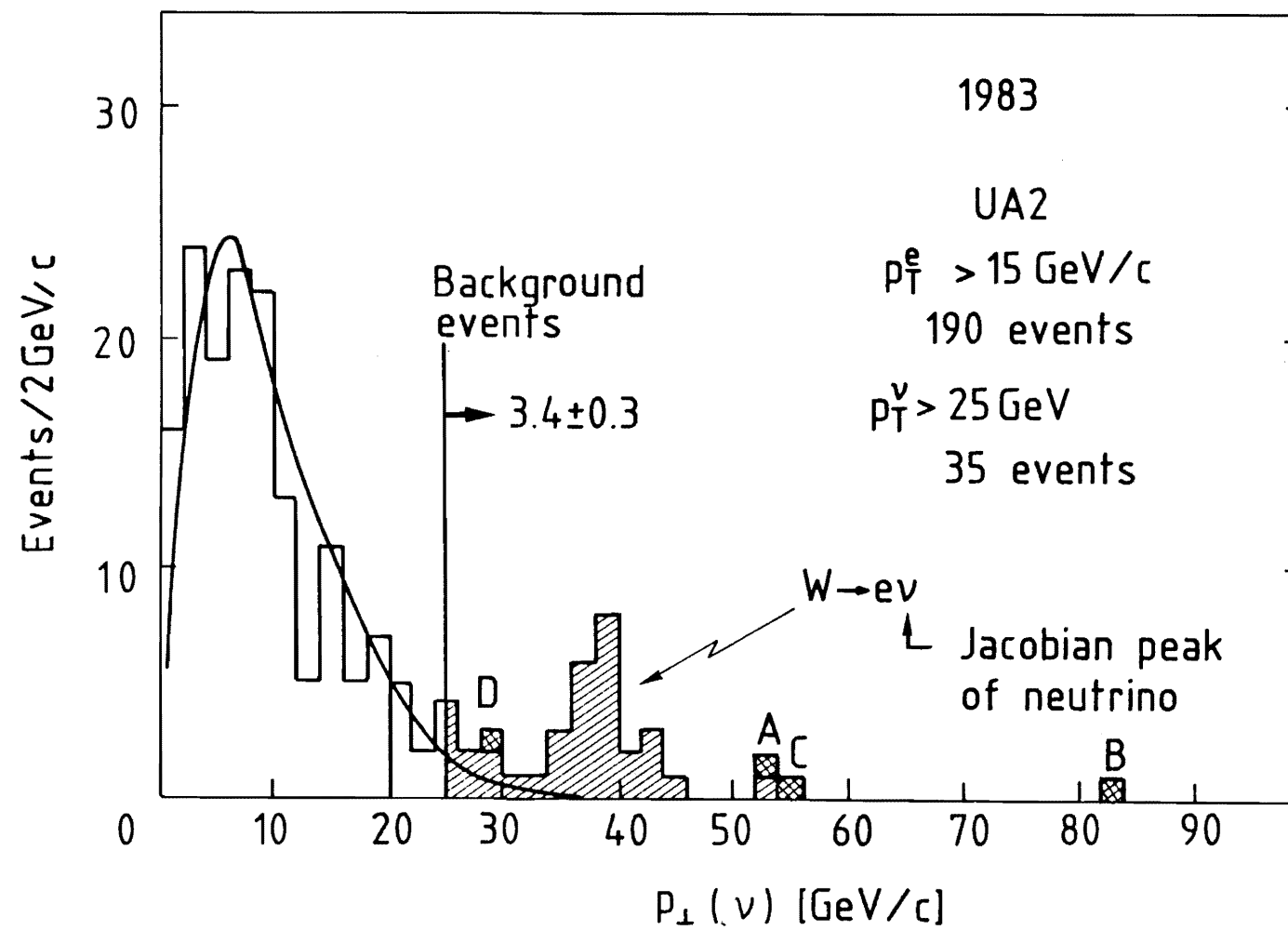


Fig. 2

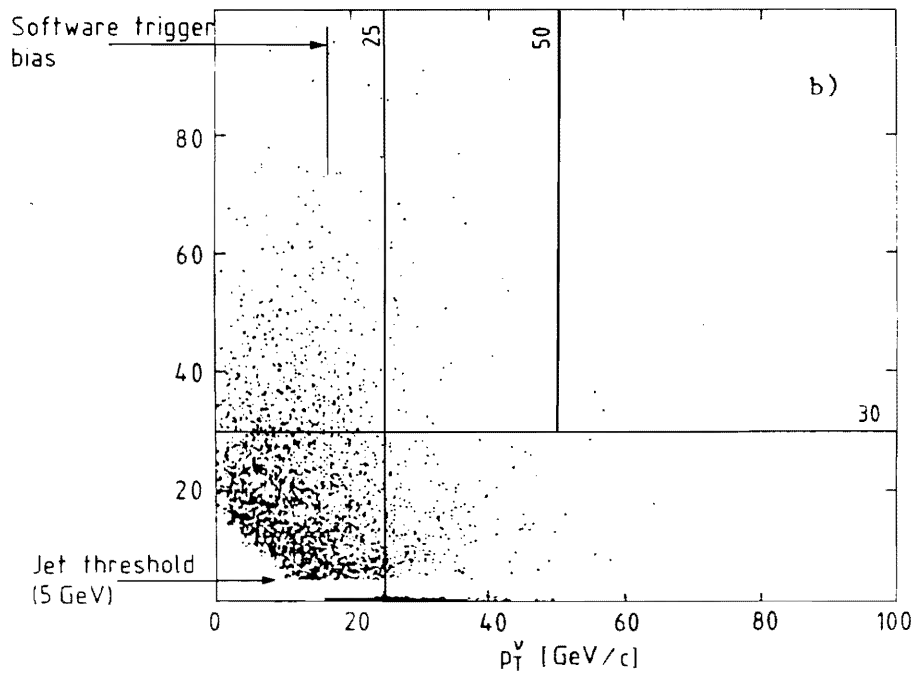
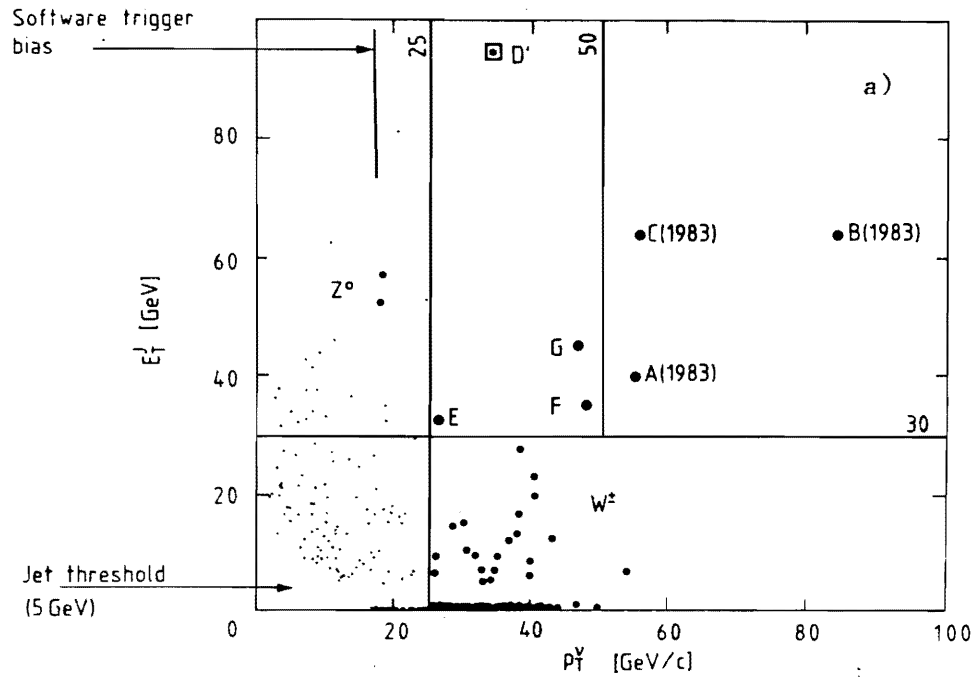


Fig. 3

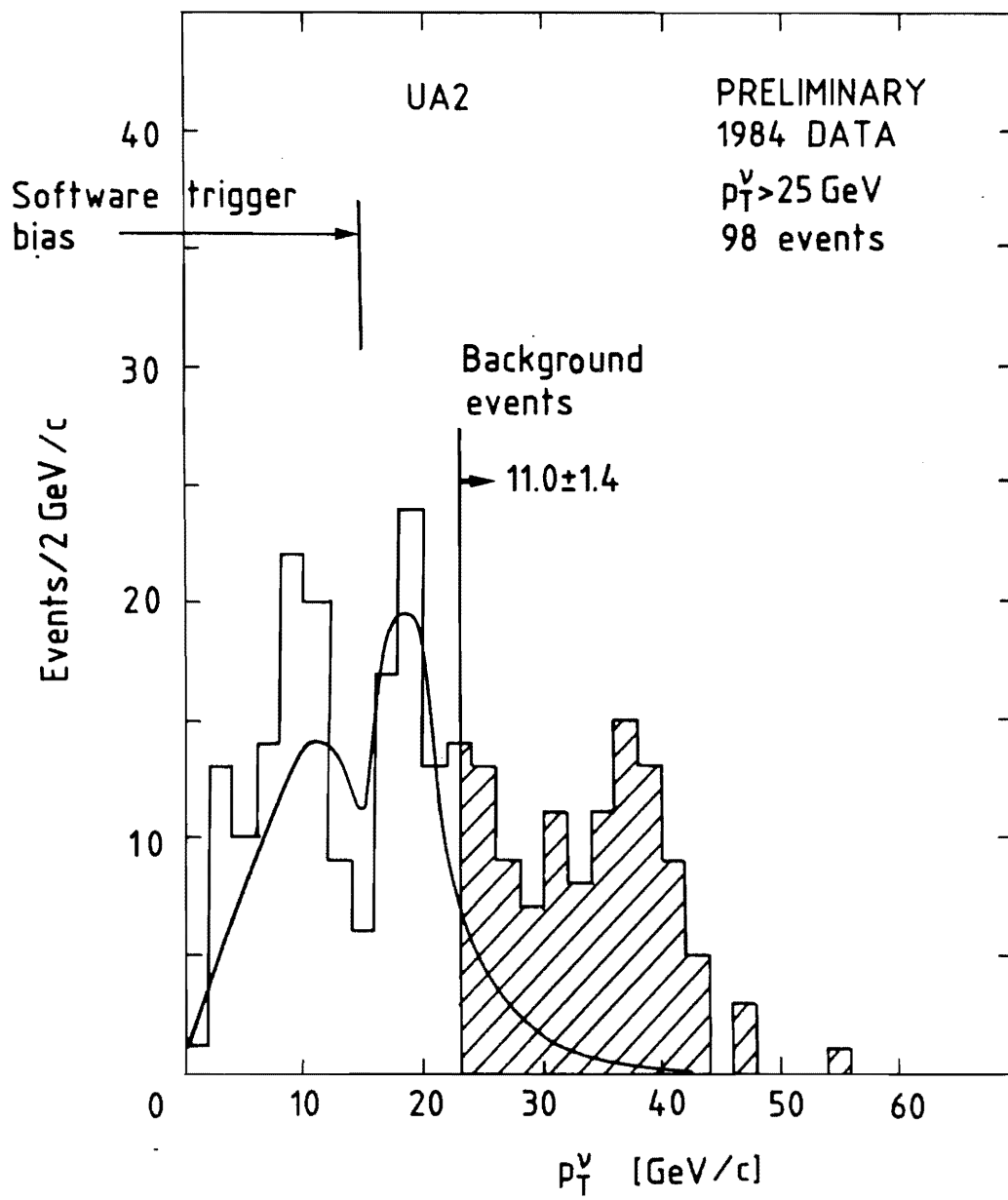


Fig. 4

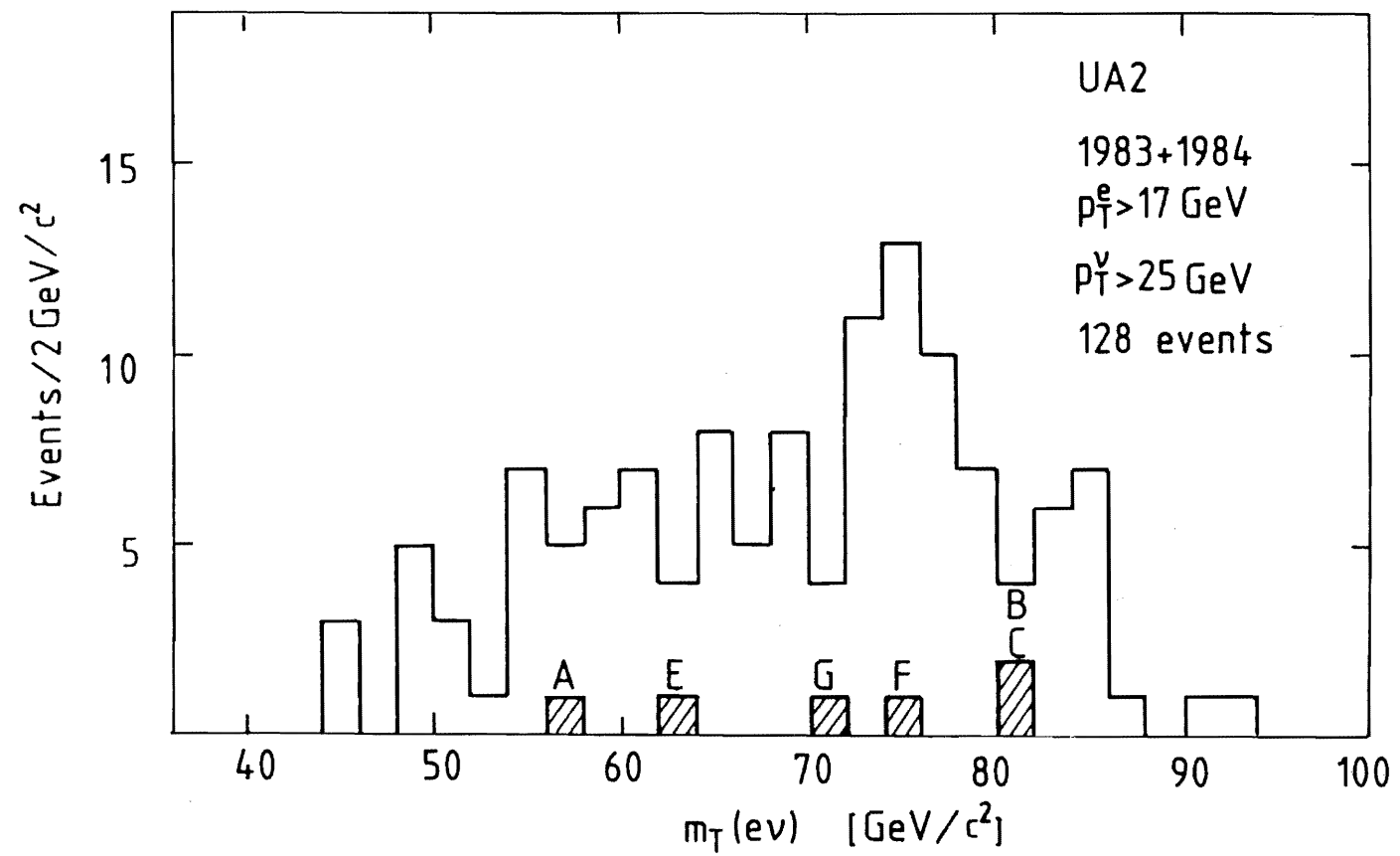


Fig. 5

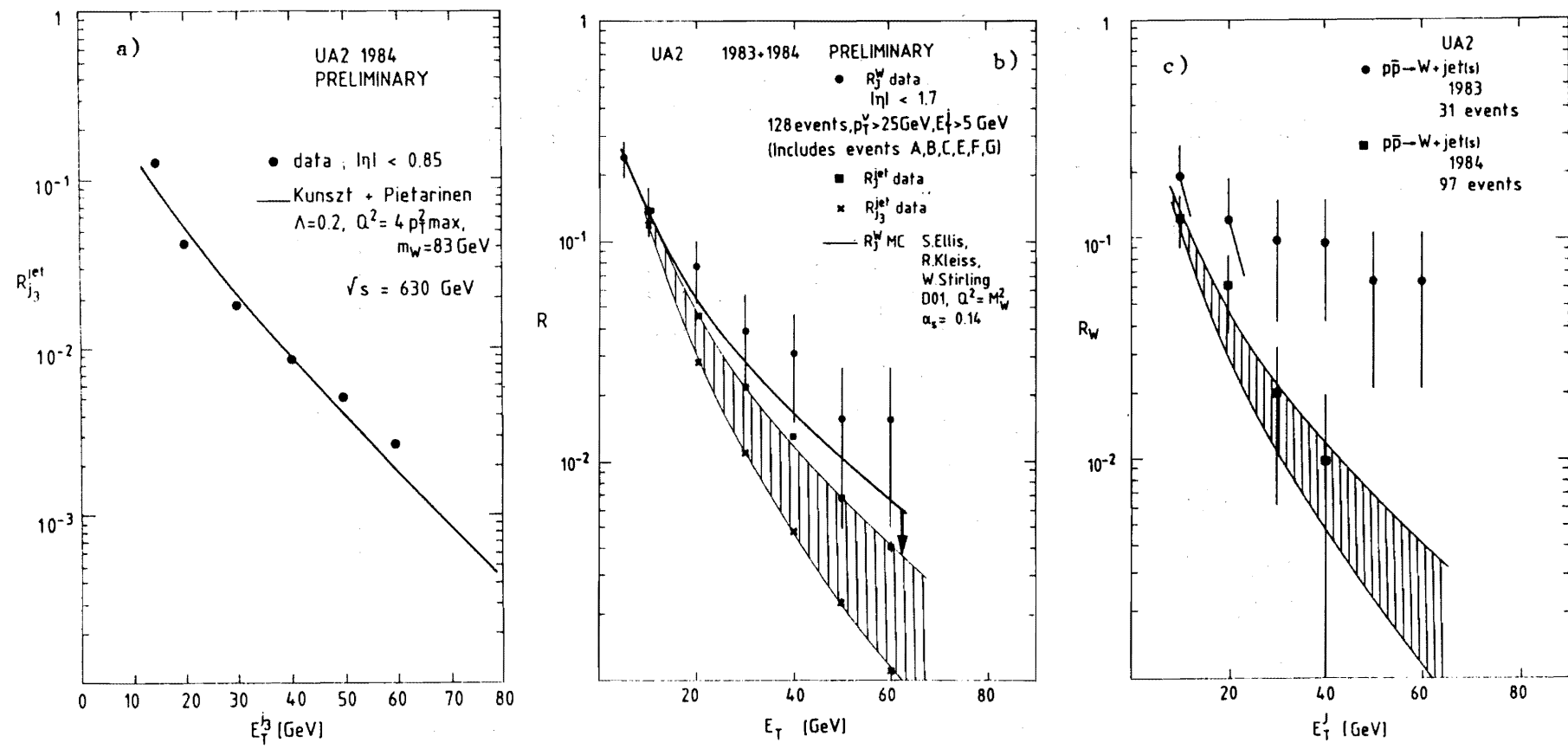


Fig. 6

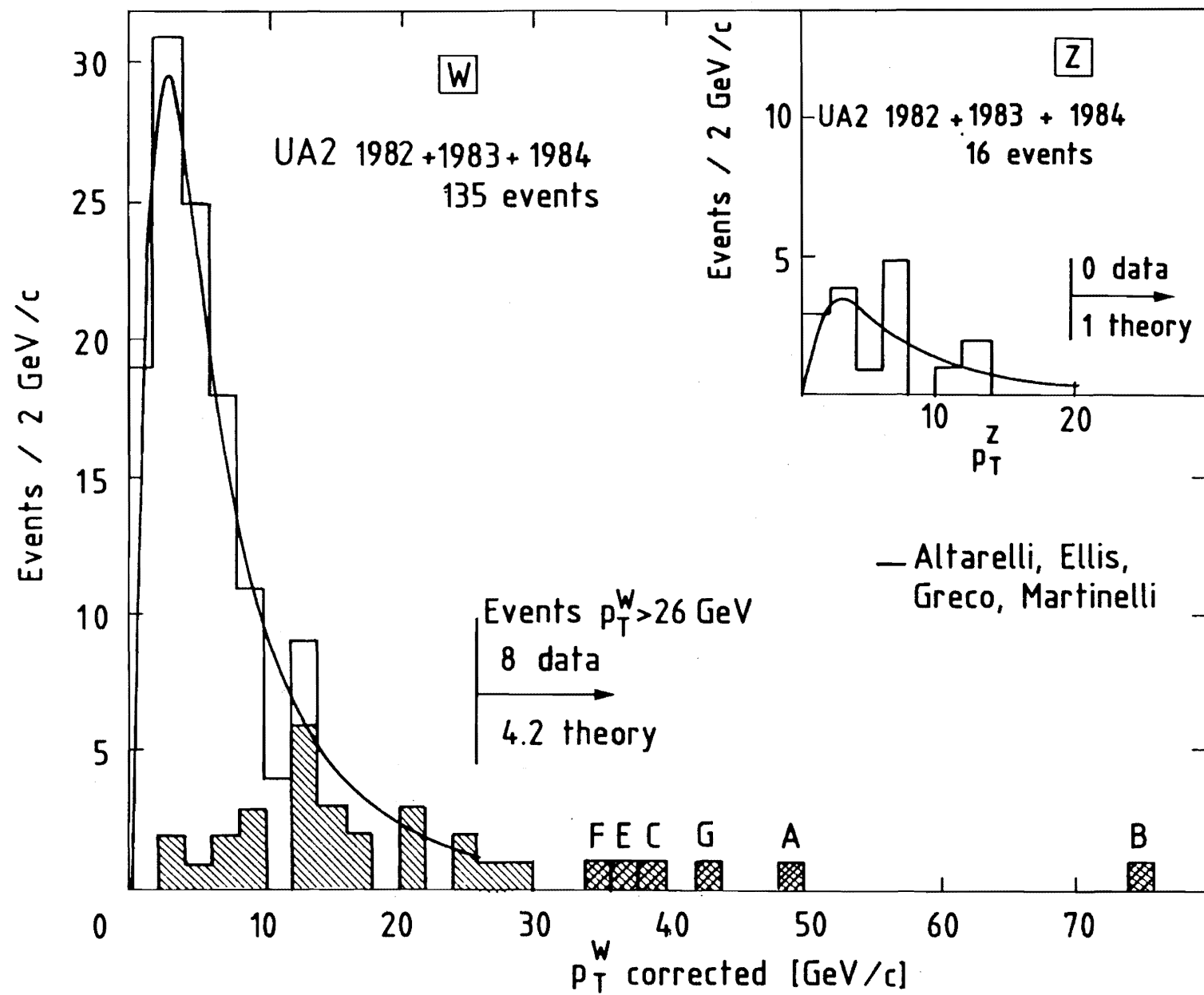


Fig. 7

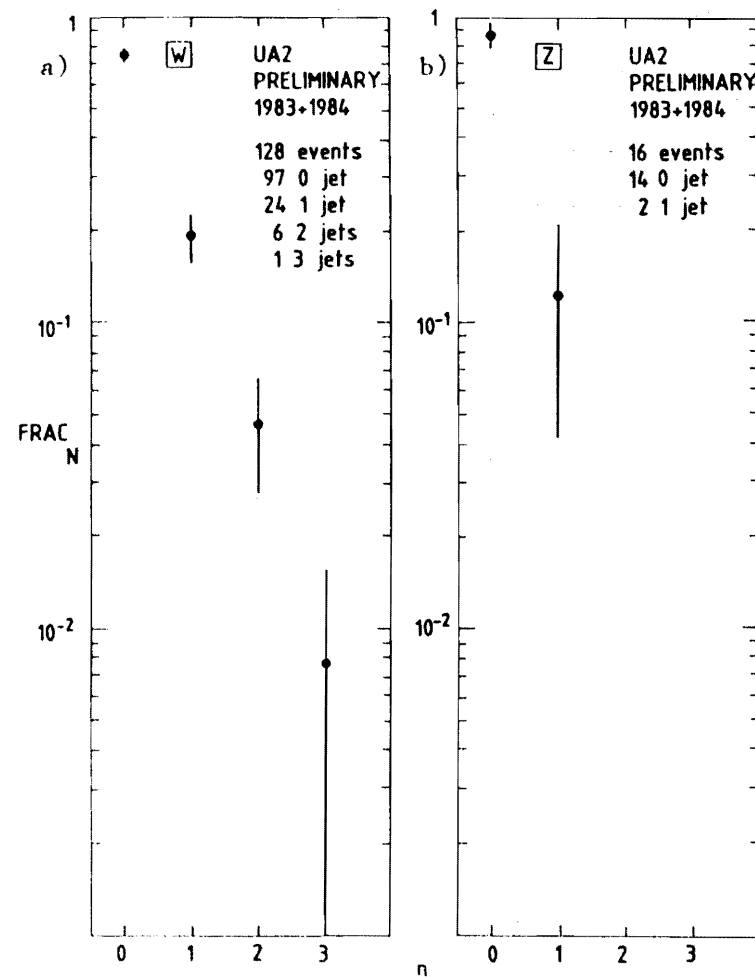


Fig. 8

