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HEAVY QUARK PRODUCTION
AT THE CERN PROTON-ANTIPROTON COLLIDER

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I. INTRODUCTION

Heavy quark production in strong interactions has been intensively studied in the c.m. energy range $20 < \sqrt{s} < 63$ GeV [1]. In $p\bar{p}$ interactions at 540 GeV c.m. energy we can study both strong and weak production of heavy flavors. We report here:

1. A search for the decays $W \rightarrow c\bar{s}$, $Z \rightarrow c\bar{c}$, $b\bar{b}$ and simultaneously for strong central production of $c\bar{c}$, $b\bar{b}$ [2];
2. observation of events which are kinematically consistent with production of a top quark of mass $30 < m_t < 50$ GeV/c² in the process: $W \rightarrow t\bar{b}$, $t \rightarrow b\bar{l}\nu$, ($l \equiv e, \mu$), [3];
3. production of the charmed D^* meson in high p_T jet fragmentation [4,5].

All the results reported here come from the 118 nb⁻¹ data recorded during the 1983 collider run.

II. SEARCH FOR $W \rightarrow c\bar{s}$, $Z \rightarrow b\bar{b}$, $c\bar{c}$

The standard electroweak model predicts that more than 70% of W's and Z's decay into quark-antiquark pairs. These two-jet modes are difficult to observe because of the large background from hard scattering of gluons, and to a lesser extent, of quarks. Figure 1 from Horgan and Jacob shows the predicted yield of jet pairs versus P_T from both strong and weak production processes [6]. We note that if at least one of the jets is required to come from a heavy quark (c,b,t), the strong production background is reduced to

a level comparable to that of W and Z decay. In the UA1 experiment, c- and b-jets are identifiable by the presence of a muon in the jet, in the (approximately) 10% of cases in which semileptonic muonic decay occurs.

We report here on a search for the processes $W \rightarrow c\bar{s}$, $Z \rightarrow b\bar{b}, c\bar{c}$ in two-jet events in which one jet contains a muon. The search for $W \rightarrow t\bar{b}$, followed by semileptonic decay of the top quark, is described in section III.

1. Event Selection

The UA1 detector and the identification of jets and muons have been described previously [7,8]. The following selection criteria were used to find W or Z decaying to c or b with subsequent semileptonic decay:

- a muon with $P_T > 8$ GeV/c;
- a nearby jet ($\phi_{\mu\text{-jet}} < 40^\circ$) with $P_T > 6$ GeV/c and $|\eta| < 2$;
- a second jet with $P_T > 10$ GeV/c and $|\eta| < 2$;
- no additional jets with $P_T > 6$ GeV/c and $|\eta| < 2$;
- a neutrino (i.e. missing transverse energy) of $P_T > 5$ GeV/c with $\phi_{\nu-\mu} < 90^\circ$; a Monte Carlo calculation shows that $\phi_{\nu-\mu}$ may be as large as 90° due to the large measurement error (typically 3.5 GeV/c for each transverse component) on missing transverse energy.

To avoid a bias towards high transverse energy events we used only events triggered by a muon. In 108 nb^{-1} of 1983 data a total of 22 events satisfied all criteria.

Jet finding in the calorimeters is done with a standard algorithm which associates electromagnetic and hadronic calorimeter modules in a cone in (η, ϕ) space of volume $(\Delta\eta^2 + \Delta\phi^2) < 1$ around the jet axis. The resulting jet energy is underestimated because some jet fragments fall outside this cone. The energy outside the cone has been calculated as a

function of E , ϕ and η of the jet [9]; it varies from roughly 20% of the total E_T at 15 GeV to 10% of E_T at 60 GeV. All jet energies in the 22 events discussed below have been corrected by the appropriate factor.

2. Results

Figure 2a shows $M(jj\mu)$, the invariant mass of the muon-jet-jet system for these 22 events. As indicated in fig. 1, this plot should contain $c\bar{c}$ and $b\bar{b}$ pairs produced by hard parton-parton scattering in addition to the W and Z decay component.

A complete neutrino momentum vector can be reconstructed on the assumption that the neutrino has the same rapidity as the associated muon-jet system. This allows an estimate of $M(jj\mu\nu)$ as shown in fig. 2b.

The dashed line in fig. 2 is a leading log QCD calculation of the distribution expected for $c\bar{c}$ and $b\bar{b}$ production [10]. The calculation incorporates scale violating structure functions and coupling constant, and the Peterson et al. heavy quark fragmentation function [11]. The resulting curve is normalized to the total number of events in the plot; this normalization requires a reduction by a factor of three of the $c\bar{c}$, $b\bar{b}$ cross sections of fig. 1; this reduction is compatible with the expected uncertainties of this QCD calculation [12].

An excess of about 5 events around 100 GeV/c² is seen above the curve in fig. 2. A Monte Carlo calculation based upon the measured cross sections for W and Z production predicts three such events in the proportions $Z(b\bar{b}): Z(c\bar{c}): W(c\bar{s})$ of 3:1:2 [10]. The dominance of $Z \rightarrow b\bar{b}$ is due primarily to the hardness of b-quark fragmentation ($\langle z \rangle_b \approx 0.8$) relative to that of the c-quark ($\langle z \rangle_c \approx 0.6$) [13]. The Monte Carlo also predicts that the experimentally observed W/Z peak will be shifted to 99 GeV/c² due to measurement errors. Figure 3 shows the track and calorimeter information for an event with $M(jj\mu\nu)$ of 103.5 GeV/c².

3. Background

The decays in flight $\pi/K \rightarrow \mu\nu$ can simulate prompt leptons. In particular the kaon decay may simulate a muon of higher momentum than the parent kaon [8]. Using the approach described in section III.3b we have verified that background from this source is negligible. A second source of background arises from the possibility of associating a relatively low p_T muon in the outer muon drift chambers with the wrong (and higher p_T) track in the same jet in the central detector. A study of this background is still in progress. However we note that both backgrounds lead to an overestimate of the muon energy; this in turn simulates a "neutrino" directly opposite the muon ($\phi_{\nu-\mu} \approx 180^\circ$). Hence these events would be removed by the $\phi_{\mu-\nu} < 90^\circ$ cut.

4. Summary

The structure around $100 \text{ GeV}/c^2$ in $M(jj\mu\nu)$ is consistent with expectations for W/Z decays to c - and b - quarks. The continuation of this study with additional data will test Standard Model predictions for W/Z decays to quarks and should also provide a calibration for multiquark spectroscopy, thereby refining the determination of the top quark mass (section III.4).

III. THE SEARCH FOR TOP

The search for the top quark in e^+e^- colliding beams has established a mass limit $m_t > 22 \text{ GeV}/c^2$ [14]. At the $Spp\bar{S}$ collider the decay channel $W \rightarrow t\bar{b}$ makes it possible to extend this search to masses of around $65 \text{ GeV}/c^2$. The signal of 68 decays $W^\pm \rightarrow e^\pm \nu$ observed in the UA1 experiment [15] implies a total of (181 ± 20) $W \rightarrow t\bar{b}$ decays (for $m_t = 40 \text{ GeV}/c^2$) in the same data sample.

We recently reported [3] the observation of 6 events which are

kinematically consistent with the process:

$$W^+ \rightarrow t\bar{b}, t \rightarrow \ell^+ \nu_b (\ell \equiv e, \mu).$$

This process has the topology: charged lepton + two jets + missing energy. The isolation of the electron or muon, due to the large Q-value in top decay, provides a distinctive signature. For a semi-leptonic branching ratio of 1/9 and the following requirements on transverse energy:

$[E_T(\bar{b}) > 8 \text{ GeV}; E_T(b) > 7 \text{ GeV}; p_T(\ell) > 12 \text{ GeV}/c]$ we expect (4 ± 0.3) events for each leptonic channel. (Additional requirements are discussed below.)

Electron and muon identification must be considerably improved with respect to the search for purely leptonic decays $W \rightarrow \ell \nu_\ell$ since now the signal is only $\sim 1/20$ of the $W \rightarrow \ell \nu_\ell$ rate. In addition the average lepton energy is a factor ~ 3 smaller, greatly enhancing the probability of a hadron simulating the charged lepton. Furthermore the presence of two jets in the event increases, relative to $W \rightarrow \ell \nu_\ell$ decay, backgrounds due to hard parton-parton scattering.

1. The Electron Sample

Electrons are identified by comparing momentum measured by magnetic curvature in the central tracking chamber with the energy deposited in the surrounding electromagnetic calorimeter. The $27 X_0$ lead/scintillator calorimeter hodoscope is segmented four times in depth ($3 X_0, 7 X_0, 10 X_0, 7 X_0$) and is followed by a hadron calorimeter in which only a small ($< 600 \text{ MeV}$) residual energy E_{had} is expected for electrons. Each of the four segments of the lead/scintillator calorimeter cells is read out by four independent photomultipliers in a way that permits the determination, by pulse division, of the centroid of the energy deposition in two orthogonal directions.

Figure 4 diagrams the initial selection process for an isolated electron with transverse energy exceeding 12 GeV/c. Isolation is enforced by specifying that a maximum of 10% of the electron energy is allowed in the cone ΔR surrounding the electron axis; $\Delta R \equiv (\Delta\eta^2 + \Delta\phi^2)^{1/2}$ where ϕ is the azimuthal angle measured in radians and η is the pseudo-rapidity. The tight requirement of less than 200 MeV leakage to the hadron calorimeter leaves us with a sample of 152 events with an "electron" and one or more jets. Simultaneously we obtain a sample of 49 $W \rightarrow e\nu_e$ events, 2723 [π^0 + jet(s)] events and 169 [$(\pi^\pm + \text{jet(s)})$] events; these jet events are used to estimate backgrounds due to strong production of jets (section III.3a).

In the sample of 152 [electron + jet(s)] events a total of 43 electrons were identified as arising from photon conversions in the beam tube and in the walls of the central drift chamber. In fig. 5 the electron parameters of the remaining 109 events are compared with those of the 49 $W \rightarrow e\nu$ events found in the same search. In fig. 5a the excess of events with $p < E$ indicates the presence of background due to neutral pions overlapping with a single charged hadron. Similarly the distributions in χ^2_G (fig. 5b), which measures the spatial matching between the electron track in the central detector and the energy deposition in the electromagnetic calorimeter, suggest the presence of the same background.

In order to eliminate this background the electron transverse energy threshold is raised to 15 GeV and the following conditions are applied:

- (i) a good match between the momentum measurement and the energy deposition in the calorimeters, $|(1/p) - (1/E)| < 3\sigma$;
- (ii) a good electromagnetic shape characterized by $\chi^2_R < 20$ for the energy depositions in the four e.m. calorimeter segments, and
- (iii) a stricter isolation requirement for the electron track, namely that

Σp_T and ΣE_T be each less than 1 GeV in a cone of $\Delta R < 0.4$ around the track; Σp_T and ΣE_T are respectively summed over the tracks and the calorimetric energy within the cone.

These cuts result in a final sample of 12 events: 7 one-jet events, 3 two-jet events and 2 three-jet events. In fig. 6 the electron parameters of the 5 multijet events are compared with those of the 49 $W \rightarrow e\nu$ events and seem to be in good agreement.

2. The Muon Sample

The "isolated muon" events must have at least one jet with E_T greater than 8 GeV and a muon satisfying the following criteria:

- transverse momentum in the central detector above 12 GeV/c with at least 30 digitizings and projected length in the bending plane > 40 cm;
- good geometrical matching between the track in the muon chambers and in the central detector;
- isolation, namely $\Sigma p_T < 0.1 p_T(\mu)$, $\Sigma E_T < 0.2 p_T(\mu)$ for $\Delta R < 0.4$.

The 40 events satisfying these criteria were scanned for $K \rightarrow \mu\nu$ decays in flight in the central detector, cosmic rays and other identifiable backgrounds. Finally an additional isolation requirement that no jet be within $\Delta R = 1$ of the muon was imposed. This left 7 one-jet, 4 two-jet and 1 three-jet events.

3. Background Studies

a) π^0 Background

The dominant background is expected to come from three-jet events in which one jet consists of a high p_T charged hadron and one or more overlapping neutral pions ("pileup"). This background has been calculated from the 169 isolated charged hadron events (fig. 4) found in the course of

the isolated electron search. This sample contained 68 events with two or more jets in addition to the $(h^\pm + n\pi^0)$ system. The background calculation used these 68 events as follows:

- (i) from the measured $p_h^\pm$, E_{had} , and $E_{e.m.}$ for a given event the π^0 energy E_{π^0} was obtained;
- (ii) the probability $P_e(E_h^\pm, E_{\pi^0})$ that the event will fluctuate to satisfy the criteria for an isolated electron was calculated using test beam data ($\pi^\pm$ beams incident on UA1 calorimeter modules) and Monte Carlo simulations of π^0 showers. This procedure gave an estimate of 0.1 background events in the (electron + two-jet) sample.

b) Decay in flight muons

Here the dominant background is expected to be three-jet events in which one jet fragments to a single charged pion or kaon which subsequently decays in flight ($\pi/K \rightarrow \mu\nu$). This background has been calculated using a 5nb^{-1} data sample collected with a relatively low threshold jet trigger: $E_T > 15$ GeV. (This trigger is satisfied by the multijet isolated muon events.) From this data the subset of events with two jets and an isolated charged hadron was used to estimate the background. The decay in flight of the isolated hadron was simulated assuming a charged hadron composition of 50% $\pi^\pm$ and 25% $K^\pm$. Simulated track digitizations were then passed through the standard track reconstruction program. This calculation gave an estimate of 0.17 background events in the (μ + two-jet) sample.

c) Charm and Beauty Production

The process:

$$g + g \rightarrow Q + \bar{Q} + g \quad (Q \equiv c, b)$$

followed by semi-leptonic decay of the c/b quark can give rise to an

(isolated lepton + two-jet) topology if the charged lepton carries most of the energy in the semi-leptonic decay. From the magnitude of the QQ production signal observed in this experiment (section II) we have verified that background from this source is negligible.

d) Kinematics of Background Events

Next we compare the kinematics of the candidate top events with 933 events ($n\pi^0 + > 2$ jets) found during the isolated electron search (fig. 4). The comparison is made in terms of the variables $\cos \theta^*$ and E_T^{out} . The variable E_T^{out} is the component of the transverse energy of $\pi^0/\ell^\pm$ perpendicular to the direction of j_1 , the highest E_T jet. The variable θ^* is defined in the rest frame of the $(\pi^0/\ell^\pm j_1 j_2)$ system where j_2 is the second highest E_T jet in the event; θ^* is the angle between the average pp beam axis and j_2 . Figure 7 shows the $|\cos \theta^*|$ distribution for (a) the jet accompanying W production and (b) the lowest E_T jet in a three-jet final state [16]. The distribution is strongly peaked towards unity reflecting the fact that the dominant source of these jets is bremsstrahlung of the incident partons.

Figure 8 shows $\cos \theta^*$ versus E_T^{out} for (a) $(\pi^0 + 2/3 \text{ jets})$ and (b) (isolated lepton + 2/3 jets) events. We note that the distribution of the isolated lepton events in fig. 8b differs considerably from the background distribution, and is in good agreement with the Monte Carlo calculation for decay of top produced in $W \rightarrow t\bar{b}$.

4. The $W \rightarrow t\bar{b}$ Hypothesis

For the final sample of candidate top events we make a cut $|\cos \theta^*| < 0.8$, and retain only two-jet events. This leaves three electron and three muon events with the estimated background reduced to 0.05 and 0.10 events respectively following the $\cos \theta^*$ cut. The parameters of these events are

listed in reference 3. Figure 9 shows an example of one of these events.

Figure 10 shows the invariant mass $m(\ell\nu_{Tj_2})$ versus $m(\ell\nu_{Tj_1j_2})$ for the six candidate top events; the missing transverse energy is assigned to a neutrino. The jet energies in this plot have been corrected as detailed in section II.1. In figure 11 the mass distributions for the six isolated lepton events are compared with the corresponding background distributions. Figure 12 shows $m(\ell\nu_{Tj_1})$ versus $m(\ell\nu_{Tj_2})$; for W decay with m_t around 40 GeV/c² one expects the top quark to be associated with the lower E_T jet in the majority of cases.

The shapes of the mass distributions in fig. 10 are consistent with the decay hypothesis $W \rightarrow t\bar{b}$ for $m_t \approx 40$ GeV/c². The observation of six top quarks from W decay in this experiment would imply a semileptonic leptonic branching ratio of 0.23 ± 0.09 or roughly double what is expected. However, the statistical error is large. Additionally Godbole and Roy have pointed out that in $p\bar{p}$ interactions at $\sqrt{s}$ of 540 GeV the weak and strong production mechanisms lead to very similar kinematic distributions for (lepton + two-jet) events [17]. Indeed if one assumes that the (lepton + three-jet) events reported here are due to strong $t\bar{t}$ production it would follow that approximately half of the (lepton + two-jet) events arise from strong production of top.

IV. D^* PRODUCTION IN JETS

The UA1 collaboration has observed charged D^* mesons in jets [4,5]. We briefly summarize these observations here.

The result comes from the subset of the 1983 "electron trigger" data which also satisfied a global E_T trigger requiring more than 60 GeV of total transverse energy in the barrel ($|\eta| < 1.5$) calorimeters. These events contain about 30% of all jets having E_T greater than 20 GeV.

In jets containing a minimum of three charged particles the $K^-\pi^+$ and $K^-\pi^+\pi^+$ mass combinations (and their charge conjugates) were formed: no particle identification was used to distinguish between K and π .

Figures 13a,b show the mass difference $\Delta M = M(K^-\pi_1^+\pi_2^+) - M(K^-\pi_1^+)$ for (a) all events, and (b) $1.83 < M(K^-\pi_1^+) < 1.92 \text{ GeV}/c^2$. Figures 13c,d show the $K^-\pi_1^+$ invariant mass distribution for (c) all events, and (d) $146 < \Delta M < 148 \text{ MeV}/c^2$. A fit of a Gaussian distribution to the peak in ΔM (fig. 13b) gives a mean of $147.0 \text{ MeV}/c^2$ and an rms deviation of $0.6 \text{ MeV}/c^2$. The shift of $1.6 \text{ MeV}/c^2$ from the standard value of $145.4 \pm 0.2 \text{ MeV}/c^2$ is associated with multiple scattering of the slow π^+ in the steel beam pipe. The fitted mean and width for the $K^-\pi^+$ peak (fig. 13d) are $1.870 \text{ GeV}/c^2$ and $23 \text{ MeV}/c^2$, compatible with the known D^0 mass and the estimated mass resolution.

The peaks in figs. 13b,d contain an estimated 20 $D^{*+} \rightarrow K^-\pi^+\pi^+$ events on a background of 8. Figure 14 shows the distribution in $z = p_D^* \cdot p_{\text{jet}} / (p_{\text{jet}})^2$ for a subset of 7 events in which there was excellent geometrical acceptance for both the charged particle jet and its corresponding calorimeter jet; p_D^* is the D^* momentum measured in the central drift chamber and p_{jet} is now the modulus of the total (charged plus neutral) jet momentum determined from the energy deposited in the calorimeter modules. The values of p_{jet} for these events range from 25 to 45 GeV/c . The sensitivity of $\langle z \rangle$ to various alternative definitions [13] for z is less than 10%.

The 20 observed $D^{*+} \rightarrow K^-\pi^+\pi^+$ decays were found in 3.4×10^3 jets having at least 3 tracks. The corresponding total number of jets was estimated to be 4.0×10^3 . The ratio $N(D^{*+})/N(\text{jet})$ is then $0.65 \pm 0.19 \pm 0.33$ for $z > 0.1$. Although the systematic error is large, with roughly equal contributions

from branching ratio and efficiency, this number of $D^{*\pm}$ per jet seems surprisingly high. And the number of D^{*0} could presumably be equal to $D^{*\pm}$. However we note that this measurement applies only to jets in events satisfying the combined electron and global E_T triggers, and may well be different for an unbiased jet selection.

Figure 14 implies a charm fragmentation which is much softer than that determined in e^+e^- annihilation, where the fragmentation distributions were found to have mean values near z of 0.6. This suggests that the charm production found here for $p\bar{p}$ collisions does not result from the fragmentation of jets initiated by a c -quark. In fact the number of observed $D^{*\pm}$ is about a factor of 10^2 higher than predicted for c -quark jets [6]. Since the jets studied here are expected to be predominantly initiated by gluons, a likely conclusion is then that the observed D^{*} production results from fragmentation of gluon jets into charm quark pairs.

Halzen and Hoyer have recently shown that the perturbative component of $gg \rightarrow gQ\bar{Q}$ exceeds the fusion process $gg \rightarrow Q\bar{Q}$ by roughly an order of magnitude [18]. They point out that an explanation of the magnitude of D^{*} production in UA1 may call for an additional non-perturbative fragmentation mechanism [19,20].

IV. CONCLUSIONS

1. The results of a search for $W \rightarrow c\bar{s}$, $Z \rightarrow b\bar{b}$, $c\bar{c}$, while of limited statistical significance, are in agreement with the expectations of the Standard Model.
2. For the topology $\ell + 2$ jets ($\ell \equiv e, \mu$) the requirement of an isolated well-identified charged lepton gives six events which are compatible with the cascade decay $W \rightarrow t\bar{b}$, $t \rightarrow \ell b\nu$. These events suggest a mass $30 < m_t < 50 \text{ GeV}/c^2$ for the top quark.

3. Copious D^* production is observed in jets of p_T above 20 GeV.

These results are from 118 nb^{-1} of data recorded in 1983 by the UA1 detector at the CERN proton-antiproton collider operated at 540 GeV c.m. energy.

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FIGURE CAPTIONS

- Fig. 1. Quark decays of Z^0 , $W^\pm$ compared with QCD quark and gluon jet production [6].
- Fig. 2. (a) $M(jj\mu)$ and (b) $M(jj\mu\nu)$ for two-jet events with a muon in one jet. (There is an additional event off scale around $190 \text{ GeV}/c^2$). The curve, which is normalized to the total number of events is a perturbative QCD calculation of $c\bar{c}$ and $b\bar{b}$ production with semileptonic decay of one quark [10].
- Fig. 3. Display of an event with $M(jj\mu\nu)$ of $103.5 \text{ GeV}/c^2$:
- (a) complete event;
 - (b) with $p_T > 1 \text{ GeV}/c$ thresholds for tracks and $E_T > 1 \text{ GeV}$ for calorimeter modules.
 - (c) energy in charged particle tracks as a function of η and ϕ .
 - (d) calorimetric energy deposition as a function of η and ϕ
- Fig. 4: The selection process for events with an isolated electron of E_T above 12 GeV .
- Fig. 5: The 109 isolated "electrons" (with arbitrary normalization) are compared with the 49 electrons in $W \rightarrow e\nu$ decay found in the same search. The comparison is made in terms of (a) the difference between the momentum p measured by magnetic curvature and the energy E measured in the electromagnetic calorimeter; (b) the parameter χ_G^2 which is a measure of the agreement between the direction of the electron measured in the central tracking chamber and in the electromagnetic calorimeter; (c) the parameter χ_R^2 which indicates if the pattern of energy deposition in the four calorimeter segments is electromagnetic and (d) the energy deposited in the hadron calorimeter behind the electromagnetic shower.

Fig. 6: Comparison of electrons with the topology [isolated electron + > 2 jets] with electrons from 49 $W \rightarrow e\nu$ decays. The comparison is made in the same four parameters as fig. 5.

Fig. 7: Distribution in the $\cos \theta^*$ for (a) $W + \text{jet}$ and (b) three-jet production. The curves are QCD predictions [16].

Fig. 8: $\cos \theta^*$ versus E_T^{OUT} for the topologies (a) ($\pi^0 + > 2$ jets), 933 events, and (b) (isolated lepton $\pm > 2$ jets), 12 events. The curves are predictions for the process $W \rightarrow t\bar{b}$, $t \rightarrow \ell b\nu$ ($\ell \equiv e, \mu$).

Fig. 9: Graphic display of calorimeter cells ($E_T > 2$ GeV) and charged tracks ($p_T > 1.5$ GeV) observed in the UA1 detector for a $W^- \rightarrow t\bar{b}$ candidate event: a) general view, and b) view looking along the beam direction.

Fig. 10: Four-body versus three-body mass distribution for the six $W \rightarrow t\bar{b}$ candidate events; $j_1 j_2$ are the higher and lower E_T jets respectively and ν_T represents the missing transverse energy vector. The curves show the expected distributions for $W \rightarrow t\bar{b}$ taking into account the experimental resolution. Allowance should be made for a systematic error arising from uncertainties in the jet reconstruction (± 10 GeV/c²).

Fig. 11: Comparison of $m(\ell\nu_T j_2)$ and $m(\ell\nu_T j_1 j_2)$ from fig. 10 with the corresponding distributions for the 933 background events in which e/μ is replaced by $n\pi^0$.

Fig. 12: $m(\ell\nu_T j_1)$ versus $m(\ell\nu_T j_2)$ for the six events with an isolated e/μ and two jets.

Fig. 13: a) ΔM distribution in the region of $M(D^{*+}) - M(D^0)$ with no $M_{K\pi}$ cut.

b) ΔM distribution for $1.83 < M_{K\pi} < 1.92$ GeV/c².

c) $M_{K\pi}$ distribution in the region of $M(D^0)$ with no ΔM cut.

d) $M_{K\pi}$ distribution for $146 < \Delta M < 148$ MeV/c².

Fig. 14: D^{*+} fragmentation distribution for $z > 0.1$. The data has been corrected for the track finding inefficiency for the π^+ from $D^{*+} \rightarrow D^0 \pi^+$. The mean value of z for $z > 0.1$ is 0.2.

Fig. 1

Fig. 2

RUN 7296 EVENT 369

Fig. 3 c,d

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8a

Fig. 8b

EVENT 7443/509

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14