A Study of the D^* Content of Jets at the CERN $p\bar{p}$ Collider*UA1 Collaboration, CERN, Geneva, Switzerland*

Aachen¹ - Amsterdam (NIKHEF)² - Annecy (LAPP)³ - Birmingham⁴ - Boston⁵ -
CERN⁶ - Helsinki⁷ - Kiel⁸ - Imperial College, London⁹ -
Queen Mary College, London¹⁰ - Madrid (CIEMAT)¹¹ - MIT¹² - Padua¹³ -
Paris (College de France)¹⁴ - Riverside¹⁵ - Rome¹⁶ - Rutherford Appleton Lab¹⁷ -
Saclay (CEN)¹⁸ - UCLA¹⁹ - Vienna²⁰ Collaboration

C. Albajar⁶, M.G. Albrow¹⁷, O.C. Allkofer^{8*}, B. Andrieu¹⁴, K. Ankoviak¹⁹,
R. Apsimon¹⁷, B. Aubert³, C. Bacci¹⁶, S. Bartha⁸, G. Bauer⁵, A. Bettini¹³,
A. Bezaguet⁶, P. Biddulph¹⁰, H. Bohn⁸, A. Böhrer¹, R. Bonino⁶, K. Bos², M. Botlo⁶,
D. Brockhausen⁸, C. Buchanan¹⁹, B. Buschbeck²⁰, G. Busetto¹³, A. Caner¹³,
P. Casoli¹³, H. Castilla-Valdez¹⁹, F. Cavanna³, P. Cennini⁶, S. Centro¹³,
F. Ceradini¹⁶, G. Ciapetti¹⁶, S. Cittolin⁶, E. Clayton⁹, D. Cline¹⁹, J. Colas³,
R. Conte¹³, J.A. Coughlan¹⁷, G. Cox⁴, D. Dau⁸, C. Daum², M. Della Negra⁶,
M. Demoulin⁶, D. Denegri¹⁸, H. Dibon²⁰, A. DiCiaccio¹⁶, F.J. Diez Hedo⁶,
L. Dobrzynski¹⁴, J. Dorenbosch², J. D. Dowell⁴, D. Drijard⁶, K. Eggert⁶,
E. Eisenhandler¹⁰, N. Ellis⁴, H. Evans¹⁹, H. Faissner¹, M. Felcini⁵, I.F. Fensome⁴,
A. Ferrando¹¹, L. Fortson¹⁹, T. Fuess¹², J. Garvey⁴, A. Geiser¹, A. Givernaud⁶,
A. Gonidec⁶, B. Gonzales^{19*}, J. M. Gregory⁴, J. Gronberg¹⁹, D.J. Holthuisen²,
M. Ikeda¹⁵, W. Jank⁶, G. Jorat⁶, M.I. Josa¹¹, D. Joyce¹⁵, P.I.P. Kalmus¹⁰,
V. Karimäki⁷, I. Kenyon⁴, A. Kernan¹⁵, R. Kinnunen⁷, M. Krammer²⁰, D. Kryn¹⁴,
F. Lacava¹⁶, S. Lammel¹, M. Landon¹⁰, Y. Lemoigne¹⁸, S. Levegrün⁸,
M. Lindgren¹⁵, D. Linglin³, P. Lipa²⁰, C. Markou⁹, M. Markytan²⁰, M.A. Marquina⁶,
R. Martinelli¹³, G. Maurin⁶, S. McMahon⁹, J.-P. Mendiburu¹⁴, A. Meneguzzo¹³,
J. P. Merlo¹⁸, T. Meyer⁶, T. Moers¹, M. Mohammadi¹⁹, K. Morgan⁵, A. Morsch⁸,
A. Moulin¹, Th. Muller⁶, R. Munoz⁶, L. Naumann⁶, P. Nedelec¹⁴, M. Nikitas⁴,
A. Nisati¹⁶, A. Norton⁶, V. O'Dell¹⁷, S. Otwinowski⁵, G. Pancheri¹², M. Passaseo¹⁶,
F. Pauss⁶, E. Petrollo¹⁶, G. Piano Mortari¹⁶, E. Pietarinen⁷, M. Pimiä⁷, A. Placci⁶,
L. Pontecorvo¹⁶, J.-P. Porte⁶, R. Prosi⁸, E. Rademacher⁶, M. Rauschkolb⁸,
H. Reithler¹, J.-P. Revol^{6,12}, S. Robins¹⁰, D. Robinson¹⁰, T. Rodrigo⁶, J. Rohlf⁵,
C. Rubbia⁶, G. Sajot¹⁴, J.M. Salicio¹¹, D. Samyn⁶, D. Schinzel¹⁶, M. Schröder²,
C. Seez⁹, T. P. Shah^{6,17}, D. Smith¹⁵, P. Sphicas⁶, D. Stork¹⁹, C. Stubenrauch⁶,
K. Sumorok¹², F. Szoncs²⁰, A. Taurok²⁰, L. Taylor⁹, S. Tether¹², G. Thompson¹⁰,
E. Torrente-Lujan¹¹, H. Tuchscherer¹, J. Tuominiemi⁷, W. van de Guchte²,
A. van Dijk², M. Vargas¹⁹, S. Veneziano¹⁶, J.P. Vialle³,
T.S. Virdee^{6,9}, W. von Schlippe¹⁰, J. Vrana¹⁴, V. Vuillemin⁶, K. Wacker¹,
S. Wimpenny¹⁵, X. Wu¹², C.-E. Wulz²⁰, M. Yvert³, I. Zacharov⁶, L. Zanella¹⁶,
Y. Zolnierowski¹³ and P. Zotto⁶.

(submitted to Physics Letters B)

(* deceased)

ABSTRACT

We have measured the rate of $D^{*\pm}$ meson production inside the jets produced in $\bar{p}p$ collisions at $\sqrt{s} = 630$ GeV. For jets in the transverse energy range $15 \text{ GeV} < E_T < 60 \text{ GeV}$ we find a production rate of $0.10 \pm 0.04 \pm 0.03$ $D^{*\pm}$ per jet, which is in good agreement with perturbative QCD calculations. In addition, we find that the $D^{*\pm}$ fragmentation distribution is strongly peaked towards low z consistent with gluon splitting as the dominant production mechanism.

1. Introduction

At the large center of mass energies of the CERN and Fermilab $\bar{p}p$ Colliders, perturbative QCD gives a good description of hadronic jet production [1, 2, 3]. The jet cross-section is dominated by the sub-process $gg \rightarrow gg$ and for the region of large jet transverse energy ($E_T > 40$ GeV), perturbative calculations predict that around 10% of the final state gluons will fragment into charmed quark pairs (i.e. $g \rightarrow c\bar{c}$) [4, 5]. Mueller and Nason have shown that the leading non-perturbative correction to this prediction is negligible and hence that a measurement of the charm quark content of a gluon jet provides a test of QCD [6].

The UA1 Collaboration has reported a measurement of $0.65 \pm 0.19 \pm 0.33$ charged D^* mesons per jet ($\langle E_T \rangle = 28$ GeV) from the analysis of data recorded in 1983 at $\sqrt{s} = 546$ GeV with an integrated luminosity of 113 nb^{-1} [7]. The shape of the $D^{*\pm}$ fragmentation distribution was found to be significantly softer than that observed in the fragmentation of primary c -quarks, consistent with the interpretation of $D^{*\pm}$ production via gluon splitting ($g \rightarrow c\bar{c}$). However the magnitude of the $D^{*\pm}$ signal was considerably higher than the corresponding QCD predictions [4, 5]. In a recent paper [8] the CDF Collaboration have reported a measurement of $0.10 \pm 0.03 \pm 0.03$ charged D^* mesons per jet ($\langle E_T \rangle = 47$ GeV) using data recorded at the Fermilab Tevatron Collider at $\sqrt{s} = 1.8$ TeV during 1987. However, no measurement of the fragmentation distribution was presented.

In this paper we report the results of a new analysis of $D^{*\pm}$ production based on jet data collected by the UA1 Collaboration during the 1984 and 1985 running periods at $\sqrt{s} = 630$ GeV [9]. The analysis separates into three parts:

- (i) A search in the 1985 data for a D^* signal in charged particle jets.
- (ii) A measurement of the ratio $N(D^{*\pm}) / N(\text{Jets})$ using calorimeter jets with $15 \text{ GeV} < E_T < 60 \text{ GeV}$.
- (iii) A measurement of the fragmentation distribution using the same sample as in (i) above. The fragmentation variable is defined as $z \equiv p(D^{*\pm}) / p(\text{jet})$, where $p(D^{*\pm})$ and $p(\text{jet})$ are the momenta of the D^* and jet respectively.

2. Data Sample and Jet Selection

During the 1984 and 1985 running periods UA1 accumulated 618 nb^{-1} of jet trigger data at $\sqrt{s} = 630$ GeV. The UA1 detector, trigger and data-taking conditions have been described at length elsewhere and we refer the reader to Refs. [1, 9] for details. Briefly, two trigger conditions were used: a localized transverse energy deposition (jet) trigger and a summed scalar transverse energy deposition (ΣE_T) trigger. Online trigger thresholds of $E_T > 25$ or 30 GeV (depending upon running conditions) for pseudorapidity $|\eta| < 3.0$ were used for the jet trigger, and $\Sigma E_T > 80$ GeV for $|\eta| < 1.5$ was used for the ΣE_T trigger. In addition, for the 1985 run a second ΣE_T trigger was used with the threshold set to $\Sigma E_T > 120$ GeV for $|\eta| < 3$. Jets were reconstructed offline using the UA1 jet algorithm [1] and events retained for further analysis if they contained at least one reconstructed calorimeter jet with $E_T > 40$ GeV in the central pseudorapidity region, $|\eta| < 1.5$. Additional cuts were made on: (i) the total visible energy in the event, $\Sigma E < 700$ GeV, and

(ii) the significance of the transverse energy imbalance, $E_T^{\text{miss}} / \sigma(E_T^{\text{miss}}) < 2.5$ to remove double interactions and beam-halo events respectively [1, 9].

3. D^* Signal

In order to identify $D^{*\pm}$ candidates we use the standard method of searching for the decay sequence $D^{*+} \rightarrow D^0 \pi_1^+$, $D^0 \rightarrow K^- \pi_2^+$ (and its charge conjugate) by plotting the mass difference $\Delta M = M(K^- \pi_1^+ \pi_2^+) - M(K^- \pi_2^+)$. Both K and π assignments were considered for each track. The search was made in reconstructed charged particle jets with transverse momentum $p_T^{\text{ch}} > 8$ GeV/c and pseudorapidity $|\eta| < 1.0$. In order to minimize background the following criteria were applied to entries in the ΔM plot:

- (i) $1.80 \text{ GeV}/c^2 < M(K^- \pi_2^+) < 1.95 \text{ GeV}/c^2$, consistent with the D^0 mass resolution in the UA1 detector.
- (ii) $p(K^- \pi_1^+ \pi_2^+) > 5 \text{ GeV}/c$. The small Q-value of the $D^{*+} \rightarrow D^0 \pi_1^+$ decay (6 MeV/c²) results in the production of a soft π_1^+ momentum spectrum with $\langle p \rangle \approx 450 \text{ MeV}/c$. The efficiency for reconstructing the slow pion declines rapidly for $p(K^- \pi_1^+ \pi_2^+)$ below 5 GeV/c.
- (iii) $p(\pi_1^+) > 0.3 \text{ GeV}/c$. This is used to reduce background from soft electrons and from pions in the underlying event.
- (iv) $\cos(\theta^*) > -0.8$ where θ^* is the decay angle of the kaon in the $K^- \pi_2^+$ rest frame. Since the D^0 is a scalar particle the distribution in $\cos\theta^*$ should be flat. When a low mass $\pi\pi$ pair is misidentified as $D^0 \rightarrow K\pi$ the $\cos\theta^*$ distribution is strongly peaked towards -1.

In addition we reject events with the K or π tracks lying within ± 20 degrees about the horizontal plane to remove the inefficient region of the UA1 central detector. We use only the data from the 1985 run (333 nb⁻¹) for which dE/dx information adequate for rejecting electrons below 1 GeV/c is available. The resulting ΔM distributions are shown in Fig. 1 for the p_T^{ch} ranges: (a) $8 \text{ GeV}/c < p_T^{\text{ch}} < 12 \text{ GeV}/c$; (b) $12 \text{ GeV}/c < p_T^{\text{ch}} < 16 \text{ GeV}/c$; (c) $16 < p_T^{\text{ch}} < 20 \text{ GeV}/c$ and (d) $p_T^{\text{ch}} > 20 \text{ GeV}/c$.

The clear peak in the $12 \text{ GeV}/c < p_T^{\text{ch}} < 16 \text{ GeV}/c$ region confirms the $D^{*\pm}$ signal reported in Ref. 7. A fit (Gaussian + background function) to the $12 \text{ GeV}/c < p_T^{\text{ch}} < 16 \text{ GeV}/c$ data gives a signal of 19.5 ± 5.5 events with a mean ΔM of $145.2 \pm 0.4 \text{ MeV}/c^2$ and an RMS deviation of $1.1 \pm 0.3 \text{ MeV}/c^2$. The mass and width are in agreement with the world average value for ΔM of $145.45 \pm 0.07 \text{ MeV}/c^2$ [10] and the experimental resolution of $1.2 \text{ MeV}/c^2$. We observe no significant signal in the other three p_T^{ch} ranges (see Table 1).

4. The ratio $N(D^*)/N(\text{Jets})$ and comparison with QCD

A measurement of the ratio $N(D^{*\pm}) / N(\text{Jets})$ has been obtained using the complete sample of 86459 jets reconstructed in the UA1 calorimeters with $15 \text{ GeV} < E_T < 60 \text{ GeV}$ and $|\eta| < 1.0$. The $D^{*+} \rightarrow K^- \pi_1^+ \pi_2^+$ signal is then sought in the matching charged-particle jets with $5 \text{ GeV}/c < p_T^{\text{ch}} < 40 \text{ GeV}/c$ using the same selection criteria as in Section 3. The charged particles within a

given calorimeter jet are identified by the requirements that they satisfy the UA1 jet algorithm [1] and that the distance in azimuth-pseudorapidity space, $\Delta R \equiv \sqrt{(\Delta\phi^2 + \Delta\eta^2)}$, between the axes of the reconstructed calorimeter and charged particle jets satisfies $\Delta R < 1$.

The resulting ΔM distribution (Fig. 2) gives a $D^{*\pm}$ signal of 25.7 ± 10.3 events with mean ΔM of 145.6 ± 0.5 MeV/c² and RMS deviation of 1.0 ± 0.3 MeV/c² consistent with the peak in Fig. 1b. By varying the form of the background function used in the fit we estimate a small additional systematic error of ± 2.0 events from the fitting procedure. We ascribe the marked decrease in the signal-to-background ratio between Figs. 1b and 2 to the following factors:

- (i) the p_T^{ch} range ($12 \text{ GeV/c} < p_T^{\text{ch}} < 16 \text{ GeV/c}$) used in Fig. 1b optimizes the D^* signal-to-background ratio. For the wider p_T^{ch} range ($5 \text{ GeV/c} < p_T^{\text{ch}} < 40 \text{ GeV/c}$) represented in Fig. 2 we expect more combinatorial background from the larger charged-particle multiplicities at high p_T^{ch} and a smaller D^* signal because of the lower production rate and reconstruction efficiency at low values of p_T^{ch} .
- (ii) dE/dx information was not used for the data in Fig. 2 because precise dE/dx information was only available for the 1985 run and because of the difficulty in reliably estimating the D^* detection efficiency when dE/dx information is used.

The efficiency for D^* detection was determined by a Monte Carlo simulation of the process $gg \rightarrow gg, g \rightarrow c \bar{c}$, followed by hadronization $c \rightarrow D^*$ [11]. Monte Carlo events were generated using ISAJET [12] and passed through the full UA1 simulation and reconstruction programs. After applying the analysis cuts we find an acceptance for the cascade decay $D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow K \pi^+$ of $(15.4 \pm 3.1)\%$ where the dominant uncertainty comes from the estimation of the D^* three-track reconstruction efficiency. Applying this efficiency and a branching ratio of $(1.84 \pm 0.35)\%$ [10] for the cascade decay leads to an estimated number of 9070 ± 3635 (stat.) ± 2601 (syst.) $D^{*\pm}$ decays where the first error comes from the number of observed $D^{*\pm}$ and the second error includes the systematic uncertainties from the acceptance calculation, the branching ratio, and the error from the ΔM fitting procedure. The corresponding calorimeter jet sample consists of 86459 jets giving:

$$N(D^{*\pm}) / N(\text{Jets}) = 0.10 \pm 0.04 \text{ (stat.)} \pm 0.03 \text{ (syst.)}$$

for $p(D^*) > 5 \text{ GeV/c}$ and an average jet transverse energy of $\langle E_T \rangle = 41 \text{ GeV}$. The first error includes all of the statistical uncertainties from the data and Monte Carlo and the second takes account of the systematic uncertainties from the fitting procedure and the branching ratio.

This result is in good agreement with a recent measurement of $0.10 \pm 0.03 \pm 0.03$ reported by the CDF Collaboration [8] for a similar average jet E_T . It is considerably lower than the original UA1 measurement of $0.65 \pm 0.19 \pm 0.33$ [7]. However, in comparing to the latter, we note that the earlier analysis used a jet sample derived from the UA1 electron trigger which may have biased the charm content of jets. In addition, the $D^{*\pm}$ signal of [7] was obtained from a sample of charged particle jets as in Fig. 1, which may have affected the $N(D^{*\pm}) / N(\text{Jets})$ ratio.

Figure 3 shows the QCD prediction for the number of charm quark pairs produced per gluon jet, $N(c\bar{c}) / N(\text{gluon jets})$ as a function of the jet E_T for $\Lambda = 290$ MeV [6]. The width of the band represents the effect of varying the charm quark mass, m_c , between 1.2 and 1.8 GeV/c². A similar uncertainty results from varying Λ between 100 and 500 MeV.

A lower limit on the ratio $N(c\bar{c}) / N(\text{gluon jets})$ can be obtained from the data. We assume that D^* production accounts for 75% of the charmed hadrons and that the charged and neutral D^* mesons are produced with equal rate. A correction is also made for the fraction of the observed jets which do not come from gluons. Using the EHLQ(2) structure function parametrizations [13] for $\sqrt{s} = 630$ GeV and $\Lambda = 290$ MeV the ISAJET Monte Carlo predicts that 70% of the observed jets come from the fragmentation of gluons. Applying these two factors and neglecting D^* production from sources other than gluon jets and slow D^* 's with $p(D^*) < 5$ GeV/c we obtain :

$$N(c\bar{c}) / N(\text{gluon jets}) > 0.05 \quad (90\% \text{ confidence level}).$$

Figure 3 compares this limit with the QCD predictions. For a mean jet E_T of 41 GeV the predictions are in agreement with our experimental result.

5. The $D^{*\pm}$ fragmentation distribution

The fragmentation variable $z \equiv p(D^{*\pm}) / p(\text{Jet})$ can be calculated for D^* events in which the charged particle jet has an associated calorimeter jet. Using the selection criteria described in Section 3, we have used the 1985 data to measure the distribution in z for the charged D^* 's in our sample. The analysis is restricted to the 1985 data sample so that dE/dx particle identification can be used to minimize the combinatorial background in the region of the ΔM peak as in Section 3.

As shown in Fig. 1 and Table 1 the D^* signal is concentrated in the jet p_T^{ch} range from 12 to 16 GeV/c, which contains 19.5 ± 5.5 events. Fig. 4 shows the fragmentation distribution, $1/N_{D^*} dN_{D^*}/dz$, for D^* candidates in jets with $12 \text{ GeV/c} < p_T^{\text{ch}} < 16 \text{ GeV/c}$ which have an associated calorimeter jet. The data points have been corrected for the momentum dependence of the $D^{*\pm}$ reconstruction efficiency. The efficiency is large for $p(D^*) > 8$ GeV/c ($\sim 85\%$) but falls rapidly as $p(D^*)$ approaches the cutoff at 5 GeV/c ($\sim 10\%$). For the data in Fig. 4 we require an efficiency of at least 20% and exclude the region $z < 0.1$ for which the acceptance is small and rapidly varying with z . This leaves the final sample of 15 events which is shown in Fig. 4.

The shape of the fragmentation distribution is consistent with the observation of [7] that the charm fragmentation function for D^* events is substantially softer than would be expected for primary c-quark fragmentation. We see no significant D^* signal for $p_T^{\text{ch}} > 16$ GeV/c where we might expect to see a signal from events with larger values of z . However we cannot exclude the production of a small number of D^* 's via primary c-quark fragmentation (see Table 1). Nonetheless, the shape of distribution in z combined with the observed production rate is consistent with the hypothesis that charmed quarks are dominantly produced by gluon splitting into $c\bar{c}$ pairs, which then hadronize into the observed $D^{*\pm}$ mesons.

6. Conclusions

We have measured the charmed quark content of jets with $15 \text{ GeV} < E_T < 60 \text{ GeV}$ in proton-antiproton interactions at $\sqrt{s} = 630 \text{ GeV}$. We find a production rate of $0.10 \pm 0.04 \pm 0.03$ D^* mesons per jet at an average jet E_T of 41 GeV. This is in agreement with perturbative QCD calculations for a gluon splitting production mechanism. Further evidence in support of the dominance of a gluon splitting mechanism comes from the shape of the $D^{*\pm}$ fragmentation distribution which is strongly peaked towards $z = 0$.

Acknowledgments

We are thankful to the management and staff of CERN and of all participating institutes for their vigorous support of the experiment. The following funding agencies have contributed to this program:

Fonds zur Förderung der Wissenschaftlichen Forschung, Austria.

Valtion luonnontieteellinen toimikunta, Finland.

Institut National de Physique Nucléaire et de Physique des Particules and Institut de Recherche Fondamentale (CEA), France.

Bundesministerium für Forschung und Technologie, Fed. Rep. Germany.

Istituto Nazionale di Fisica Nucleare, Italy.

Science and Engineering Research Council, United Kingdom.

Stichting Voor Fundamenteel Onderzoek der Materie, The Netherlands.

Department of Energy, United States of America.

The Natural Sciences and Engineering Research Council of Canada.

Thanks are due to the following people who have worked with the collaboration in the preparations for and data collection on the runs described here: L. Baumard, F. Bernasconi, D. Brozzi, V. Cecconi, R. Conte, L. Dumps, G. Fetchenhauer, G. Gallay, S. Lazic, J. C. Michelon, S. Pavlon and L. Pollet.

REFERENCES

- [1] C. Albajar et al. (UA1 Collaboration), Nucl. Phys. **B309** (1988) 405;
G. Arnison et al. (UA1 Collaboration), Phys. Lett. **B177** (1986) 244, Phys. Lett. **B172** (1986) 461, Phys. Lett. **B136** (1984) 294, Phys. Lett. **B132** (1983) 214, Phys. Lett. **B123** (1983) 115.
- [2] R. Ansari et al. (UA2 Collaboration), Phys. Lett. **B186** (1987) 452;
J. Appel et al. (UA2 Collaboration), Phys. Lett. **B160** (1985) 349;
P. Bagnaia et al. (UA2 Collaboration), Phys Lett. **B138** (1984) 430, Z. Phys. **C20** (1983) 117;
M. Banner et al. (UA2 Collaboration), Phys. Lett. **B118** (1983) 115.
- [3] F. Abe et al. (CDF Collaboration), Phys. Rev. Lett. **62** (1989) 613, Phys. Rev. Lett. **62** (1989) 3020, Phys. Rev. Lett. **64** (1989) 159.
- [4] Z. Kunszt and E. Pietarinen, Nucl. Phys. **B164** (1980) 45.
- [5] F. Halzen and F. Herzog, Phys. Rev. **D30** (1984) 2326;
F. Halzen and P. Hoyer, Phys. Lett. **154B** (1985) 324;
V. Barger and R. Philips, Phys. Rev. **D31** (1985) 215;
G. Köpp, J.H. Kühn and P. Zerwas, Phys. Lett. **153B** (1985) 315;
A. Ali and G. Ingelman, Phys. Lett. **156B** (1985) 111.
- [6] A. H. Mueller and P. Nason, Phys. Lett. **157B** (1985) 226.
- [7] G. Arnison et al. (UA1 Collaboration), Phys. Lett. **147B** (1984) 222.
- [8] F. Abe et al. (CDF Collaboration), Phys. Rev. Lett. **64** (1989) 348.
- [9] For additional details see M. Ikeda, Ph.D. Thesis, University of California (Riverside), August 1989.
- [10] Particle Data Group, Phys. Lett. **B204** (1988) 1.
- [11] Since $(gg \rightarrow gg) / (gg, q\bar{q} \rightarrow c\bar{c}) \approx 100$ in the E_T range under study the flavor creation process was not generated. See for example: R. Horgan and M. Jacob, Nucl. Phys. **B179** (1981) 441. As discussed in Section 5 the observed D^* momentum distribution is also consistent with a negligible contribution for gg and $q\bar{q}$ fusion.
- [12] F. Paige and S. D. Protopopescu, ISAJET Monte Carlo, BNL 38034 (1986).
- [13] E. Eichten, I. Hinchliffe, K. Lane and C. Quigg, Rev. Mod. Phys. **56** (1984) 579.

FIGURE CAPTIONS

- Fig. 1** ΔM distributions, $M(K^-\pi_1^\pm\pi_2^+) - M(K^-\pi_2^+)$, for the 1985 data sample. The plots correspond to searches for $D^{*\pm}$ in charged particle jets in the momentum ranges: (a) $8 \text{ GeV}/c < p_T^{\text{ch}} < 12 \text{ GeV}/c$; (b) $12 \text{ GeV}/c < p_T^{\text{ch}} < 16 \text{ GeV}/c$; (c) $16 < p_T^{\text{ch}} < 20 \text{ GeV}/c$; (d) $p_T^{\text{ch}} > 20 \text{ GeV}/c$.
- Fig. 2** ΔM distribution, $M(K^-\pi_1^\pm\pi_2^+) - M(K^-\pi_2^+)$, for the $D^{*\pm}$ search made using calorimeter jets.
- Fig. 3** QCD predictions for the number of charmed quark pairs per gluon jet as a function of the jet E_T from [6] taking $\Lambda = 290 \text{ MeV}$. The two curves show the effect of varying the charmed quark mass between 1.2 and $1.8 \text{ GeV}/c^2$. The experimental lower limit shown is derived from Fig. 2 (see text).
- Fig. 4** The charged D^* fragmentation distribution for the 15 $D^{*\pm}$ candidates which pass all of the selection criteria (see text).

D* Event Samples				
a) charged particle jets				
p_T^{ch} range (GeV/c)	Signal (events)	Background (events)	$\overline{\Delta M}$ (MeV/c ²)	σ (MeV/c ²)
$8 < p_T^{\text{ch}} < 12$	3.1 ± 4.2	8.6	—	—
$12 < p_T^{\text{ch}} < 16$	19.5 ± 5.5	7.5	145.2 ± 0.4	1.1 ± 0.3
$16 < p_T^{\text{ch}} < 20$	4.8 ± 4.4	8.1	—	—
$p_T^{\text{ch}} > 20$	-1.8 ± 4.6	18.5	—	—
b) calorimeter jets				
E_T range (GeV)	Signal (events)	Background (events)	$\overline{\Delta M}$ (MeV/c ²)	σ (MeV/c ²)
$15 < E_T < 60$	25.7 ± 10.3	36.3	145.6 ± 0.5	1.0 ± 0.3

Table 1
Summary of D* samples

Fig.1

Fig.2

Fig.3

Fig.4