Fermi National Accelerator Laboratory

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A Measurement of D* Production in Jets from $\bar{p}p$ Collisions at $\sqrt{s}$ = 1.8 TeV*

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ABSTRACT

The production rate of charged D* mesons in jets has been measured in 1.8 TeV $\bar{p}p$ collisions at the Fermilab Tevatron Collider with the CDF detector. In a sample of approximately 32,300 jets with a mean transverse energy of 47 GeV obtained from a 1987 exposure of 21.1 nb^{-1}, a signal corresponding to 25.0±7.5(stat)±2.0(sys) $D^{*\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$ events is seen above background. This corresponds to a ratio $N(D^{*+} + D^{*-})/N(\text{jet}) = 0.10 \pm 0.03 \pm 0.03$ for D* mesons with fractional momentum z greater than 0.1.

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The multiplicity of heavy quarks in jets can be calculated in perturbative QCD [1], and the leading non-perturbative correction is believed to be extremely small [2]. A substantial deviation from the predictions of QCD would therefore be interesting. The UA1 Collaboration has measured the production rate of charged D^* mesons in jets at a center-of-mass energy $\sqrt{s} = 546$ GeV [3,4]. In a measurement based on 1983 data [3], the ratio $N(D^{*\pm})/N(\text{jet})$ was observed to be $0.65\pm0.19(\text{stat})\pm0.33(\text{sys})$ for D^*s with fractional momentum $z > 0.1$ where $N(D^{*\pm}) = N(D^{*+} + D^{*-})$. The measurement was repeated [4] with the 1984 data, resulting in the ratio $N(D^{*\pm})/N(\text{jet})=$ $0.08\pm0.02\pm0.04$. In this letter we present a measurement of D^* production in jets produced at $\sqrt{s} = 1.8$ TeV using the Collider Detector at Fermilab (CDF).

The measurement of D^* production in jets from hadronic interactions probes a mechanism different from that in e^+e^- collisions. In e^+e^- collisions the production is dominated by jets initiated by c or b quarks whereas in $\bar{p}p$ collisions one expects to observe D^*s produced primarily from gluon splitting into $c\bar{c}$ or $b\bar{b}$ pairs [1]. A lowest order parton model calculation [5] indicates that approximately 75% of all jets produced at $\sqrt{s} = 1.8$ TeV with transverse energy (E_t) between 40 and 60 GeV, where both jets are in the pseudorapidity [6] region $|\eta| < 0.8$, come from gluons in the final state, compared to 0.7% from primary c quarks. Thus even though gluon splitting is a higher order process, it is expected to be the dominant mechanism for D^* production in jets.

We mention here briefly those parts of the CDF detector [7] most relevant to this study. Vertex time projection chambers just outside the beam pipe are used to determine the position of the event vertex along the beam direction. Charged particle momentum information is provided by the Central Tracking Chamber (CTC) which is immersed in a 1.5T magnetic field and provides full coverage in the pseudorapidity region $|\eta| < 1$. For vertex constrained tracks, the transverse momentum resolution is estimated to be $\delta p_t/p_t \approx \sqrt{(0.0012p_t)^2 + (0.004)^2}$ where p_t is measured in units of GeV/c. The angular resolution is approximately $\delta\phi \approx \sqrt{(0.3)^2 + (1/p_t)^2}$ mrad in the azimuthal angle and $\delta(\cot\theta) \approx 0.0022$ in the polar angle. These values were obtained for Monte Carlo tracks which were injected into real data. The CTC is surrounded by the central calorimeter, which consists of a lead-scintillator electromagnetic portion followed by a steel-scintillator hadronic compartment. For the jets used in this analysis, the E_t resolution [8] has an approximately Gaussian shape with a standard deviation (σ) of 8 GeV for 50 GeV jets.

This work is based on an integrated luminosity of 21.1 nb^{-1} ($\pm$ 15%) from the 1987 run at the Fermilab Tevatron during which a total of 26.9 nb^{-1} was collected. The events used in this analysis passed a hardware trigger that required a minimum total E_t summed over calorimeter towers in coincidence with at least one particle in each of the upstream and downstream scintillation counters. In the region $1.0 < |\eta| < 4.2$, only the electromagnetic calorimeters were included in the trigger. The E_t thresholds were set at 20,30,40 and 45 GeV depending on the luminosity. A total of 1.5×10^5 such triggers were recorded. Jets were identified according to a fixed-cone clustering algorithm [9] with a cone size [10] of $\Delta R = 1.0$. The events were then required to have at least one jet with E_t greater than 20,25,40, or 40 GeV depending on the trigger threshold. In addition, the event vertex was required to be within 60 cm of the center of the detector along the beam axis. These criteria were satisfied by approximately 38,300 events.

Jets were required to have $0.1 < |\eta| < 0.8$ where η is the centroid in pseudorapidity as measured from the center of the detector. The energies of these jets were corrected [9] for nonlinear calorimeter response, energy deposited in uninstrumented regions, energy lost outside the clustering cone and the energy added from the "underlying event", i.e. that energy which is not associated with the hard parton scattering. The correction typically increased the jet E_t by 25%. The jets were then required to have corrected $E_t > 30$ GeV. The data sample consisting of approximately 32,300 jets is summarized in Table 1.

The D^* search was performed using the standard scheme [11] where one looks for the decay sequence $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$ as well as the charge conjugate modes. The small Q value in the D^* decay to $D^0\pi$ provides a powerful handle on background rejection. However, the combined branching ratio for the decay sequence is 2.4% [12] so that, even with good reconstruction efficiency for D^*s, one needs a large sample of jets to observe a D^* signal.

Charged particle tracks in the CTC were reconstructed and constrained to the event vertex. The tracks were required to have $p_t > 0.3$ GeV/c and $|\eta| < 1.2$. Loose track selection criteria based on the number of hits and the number of segments on the track were then applied. K-π and K-π-π mass combinations were then formed where both kaon and pion assignments were tried for all tracks. To associate the K-π-π system with a jet, the momentum of the system was required to be such that its rapidity (assuming a D^* mass) with respect to the jet axis was positive. In cases of ambiguity, the closest jet (i.e. the one which maximized the D^* rapidity) was chosen. The following additional cuts were then applied (see Table 2):

1) For each K-π combination, we required $|M_{K\pi} - M_{D^0}| < 3\delta$ where δ is the uncertainty on $M_{K\pi}$ computed by propagating the track parameter uncertainties (quoted earlier in this letter) for the K and the π. δ differs slightly from one standard deviation in $M_{K\pi}$ because correlations between track parameters were ignored. For Monte Carlo D^*s, δ ranges from 4 to 70 MeV/c^2 with a mean of 19 MeV/c^2.

2) The polar angle of the kaon momentum vector in the D^0 rest frame was required to have $|\cos\theta^*| < 0.8$. This cut preferentially rejects background events since the typical opening angle between tracks in jets is small compared to the opening angle between the daughters of D^0 decays.

3) The fractional momentum of the K-π-π system, $z \equiv p_L(K\pi\pi)/E_{jet}$ (evaluated in the lab frame), was required to be greater than 0.1. The quantity $p_L(K\pi\pi)$ is the

longitudinal component of the momentum of the K-π-π system along the jet axis.

Figure 1a shows the mass difference $\Delta M = M_{K\pi\pi} - M_{K\pi}$ after all the cuts. A control sample, shown in the inset, is obtained from the "wrong-sign" mass combinations, i.e. $K^{\pm}\pi^{\mp}\pi^{\pm}$ with the same cuts. A clear excess is seen in the bin centered at 145.3 MeV/c^2, consistent with the world average value for the D*-D^0 mass difference of 145.45±0.07 MeV/c^2 [13]. As a further check of the background, the ΔM distribution for the "sidebands", where $3\delta < |M_{K\pi} - M_{D^0}| < 6\delta$, was examined. The distribution was found to be smooth and consistent with the wrong-sign distribution. To estimate the background under the peak, the ΔM distribution of Fig. 1b was fit to a Gaussian distribution in the peak region along with a background distribution parametrized as $a(\Delta M - m_\pi)^b$. Simultaneously the fit was performed on the wrong-sign distribution without the Gaussian term. Defining our D* signal region by 144.5 $< \Delta M <$ 146.5 MeV/c^2, we estimate that there are 25 $D^{*\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$ events on a background of 25 events, with a statistical uncertainty of ±7.5 events. The systematic uncertainty on the background subtraction was estimated to be ±2 events by fitting with and without the wrong-sign distribution and by varying the fitting function and the region over which the fit was performed. For the distribution of Fig. 1b the parameters for the Gaussian are a mean of 145.2 ± 0.2 MeV/c^2 and a σ of 0.56 ± 0.18 MeV/c^2 where the uncertainties are statistical only. The width of the Gaussian is consistent with Monte Carlo expectations.

The efficiency was determined as a function of jet E_t, the fragmentation variable z, and the charged particle multiplicity by reconstructing Monte Carlo D* tracks which were injected into real jet data. Folding in the observed jet E_t spectrum, we obtained the efficiency as a function of z as shown in Fig. 2 for two values of the track multiplicity. The average efficiency for $z > 0.1$ was derived by folding in the observed z distribution for D*s, obtained by breaking up the ΔM distribution into (coarse) z bins and computing an excess of D* events above background for each bin. For $z > 0.1$ an average efficiency of 37±9% was obtained where the uncertainty is dominated by systematics. The major sources of uncertainty are our insufficient knowledge of the charged particle multiplicity in events in which D*s are produced, and the uncertainty in the mass resolution for low momentum D*s.

Using a Monte Carlo, we estimate that the true number of events produced with $z > 0.1$ differs from the number observed by a multiplicative factor of 1.1±0.2 due to the jet E_t resolution and the uncertainty in the jet energy scale. The uncertainty in the correction factor was estimated by varying the energy scale, the shape of the z distribution and the magnitude of the jet E_t resolution.

To derive the number of $D^{*\pm}$ per jet, the number of $D^{*\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$ decays observed was corrected for the efficiency (see Table 2) and for the jet E_t resolution. Using the latest MARK III branching ratios [12], we obtain $N(D^{*\pm})/N(\text{jet})=$ 0.10±0.03±0.03 for $z > 0.1$. We note that the observed D*s are concentrated at low values of z; approximately 70% of the observed signal is between $z = 0.1$ and $z = 0.2$.

Within the limited statistics, this is consistent with a previous UA1 measurement [3].

In summary, we have observed $D^{*\pm}$ production in jets produced in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV. In a sample of 32,300 jets corresponding to an integrated luminosity of 21.1 nb^{-1}, 25 $D^{*\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}$ events were observed above a background of 25 events. The probability that a background of 25 events fluctuates to ≥ 50 events is 7×10^{-6}. The measured rate corresponds to a ratio $N(D^{*+} + D^{*-})/N(\text{jet}) = 0.10 \pm 0.03(\text{stat}) \pm 0.03(\text{sys})$ for D*s with fractional momentum $z > 0.1$ in jets with an average E_t of 47 GeV. This is consistent with previous measurements by the UA1 Collaboration [3,4] at $\sqrt{s} = 546$ GeV for jets with an average E_t of 28 GeV. Estimates from QCD which predict $N(D^{*\pm})/N(\text{jet})$ to be around 0.05 [1] are consistent with this result.

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Trigger Threshold (GeV)	Number of events: ($\times 10^3$) After event selection	Number of jets: ($\times 10^3$) After jet selection	Avg. Jet E_t (GeV)
20	1.6	0.7	39.0
30	28.4	23.8	42.7
40	4.0	3.7	58.8
45	4.3	4.1	59.7
Total	38.3	32.3	46.6

Table 1: The event sample used in this analysis, separated by triggers. The rightmost column shows the average corrected E_t of the jets in each trigger sample.

	Number of track combinations	Efficiency for D*s ($z > 0.1$)
$p_t > 0.3$ GeV/c, $\|\eta\| < 1.2$	...	0.85±0.04
Track reconstruction	...	0.64±0.10
$1500 < M_{K\pi} < 2400$ MeV/c^2, $138 < \Delta M < 178$ MeV/c^2	4.54×10^4	...
$\|M_{K\pi} - M_{D^0}\| < 3\delta$, $144.5 < \Delta M < 146.5$ MeV/c^2	90	0.78±0.09
$\|\cos\theta^*\| < 0.8$	61	0.84±0.02
z>0.1	50	...
After all cuts	50	0.37±0.09

Table 2: The effect of the cuts applied to the tracks in this analysis. The efficiency of each of the cuts for D*s which were reconstructed with $z > 0.1$ is also listed.

Figure Captions

Fig. 1. (a) The mass difference $\Delta M \equiv M_{K\pi\pi} - M_{K\pi}$ after all the cuts. The dotted line is the same background function as shown in fig. 1b. The inset shows the mass difference for the wrong-sign mass combinations, i.e. the combination $K^{\pm}\pi^{\mp}\pi^{\pm}$ instead of $K^{\mp}\pi^{\pm}\pi^{\pm}$. (b) The mass difference shown in finer detail in the region of the peak. The curve is a fit to a Gaussian distribution plus a background function parametrized as $a(\Delta M - m_{\pi})^{b}$.

Fig. 2. The overall efficiency for D^{*}s as a function of the fragmentation variable z for different track multiplicities in jets. The crosses show the efficiency for average jets and the open circles show the efficiency for jets with multiplicities typically two times higher.

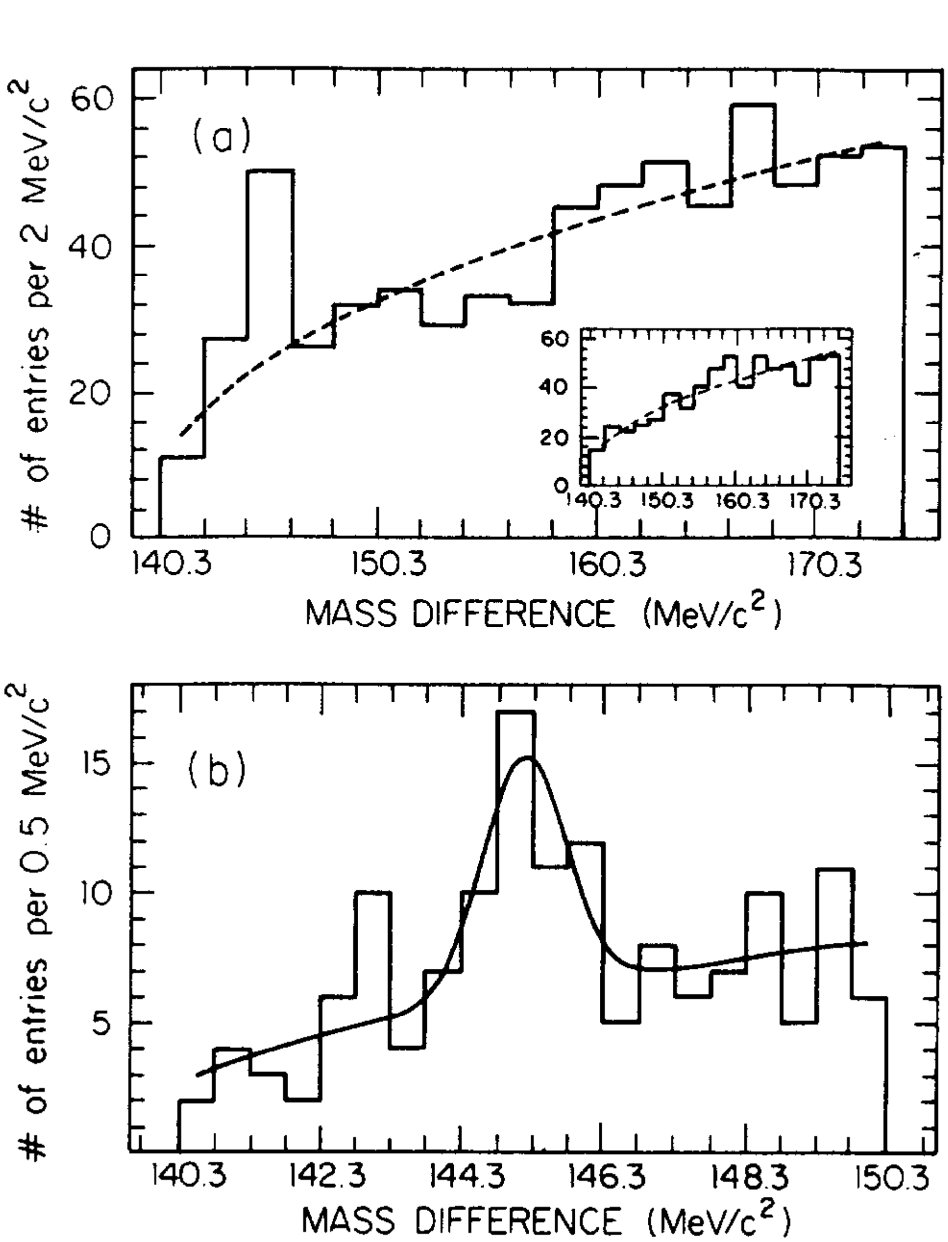
(a)
# of entries per 2 MeV/c^2
0
20
40
60
140.3
150.3
160.3
170.3
MASS DIFFERENCE (MeV/c^2)
(b)
# of entries per 0.5 MeV/c^2
5
10
15
140.3
142.3
144.3
146.3
148.3
150.3
MASS DIFFERENCE (MeV/c^2)

Figure 1

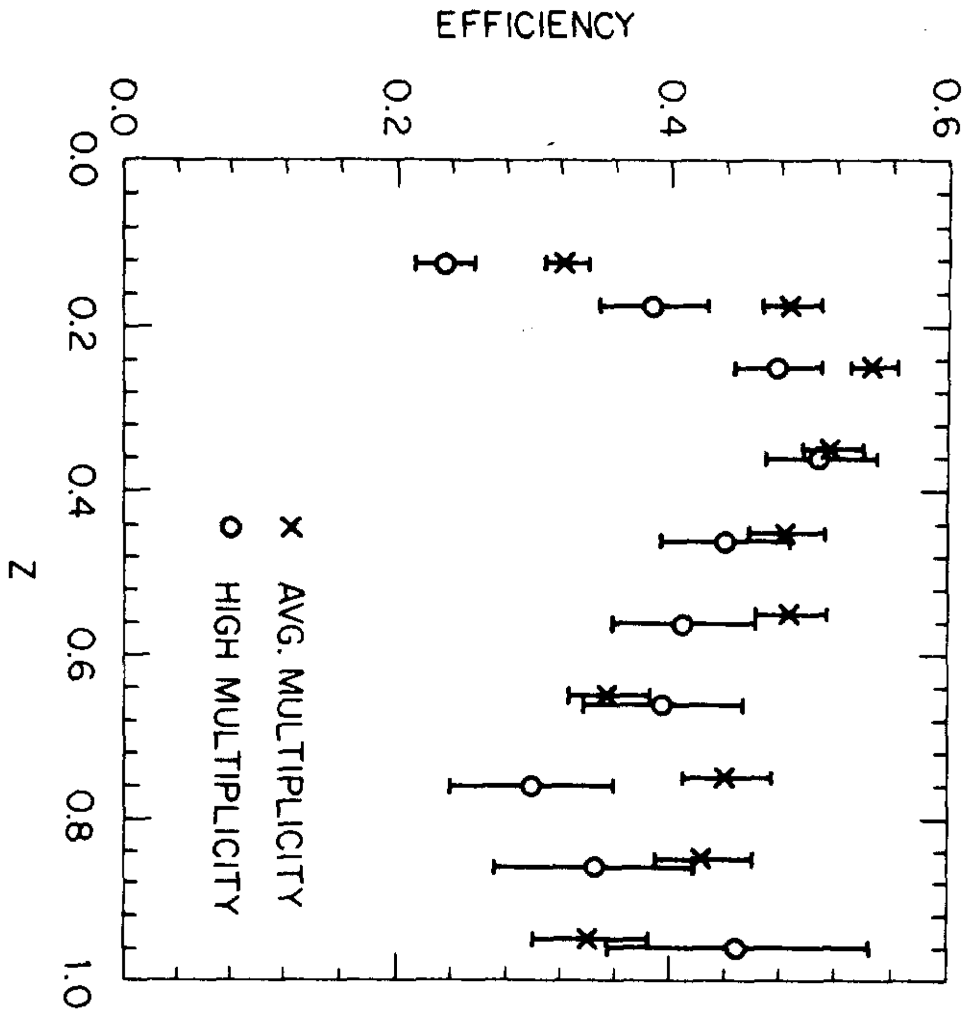
EFFICIENCY
0.0
0.2
0.4
0.6
Z
0.0
0.2
0.4
0.6
0.8
1.0
AVG. MULTIPLICITY
HIGH MULTIPLICITY

Figure 2