The Structure of Charm Jets in Deep-Inelastic Scattering

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Abstract. The structure of charm jets in deep-inelastic scattering (DIS) is studied with the H1 detector at HERA using an integrated luminosity of 50 pb^{-1}. The charm events are tagged by a D^*-meson. The events are required to have at least one jet containing the D^*-meson (D^*Jet). A second jet (*Other*Jet) is also studied, if present. The structure of these jets is investigated by measuring jet shapes and subjet multiplicities as well as the angular distribution of a subjet defined to give a correlation with a corresponding gluon at the parton level. The study of the latter distribution and its dependence on the jet energy is motivated by the suppression of soft gluon radiation from heavy quarks, as expected from QCD. All data are reasonably well described by a QCD model for charm production as implemented in RAPGAP and JETSET.

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INTRODUCTION

Jets initiated by heavy quarks are expected to be different from those initiated by light quarks. In the case of heavy quarks, the phase space available for gluon emissions is reduced due to kinematic effects of the heavy quark mass [1].

In this analysis the structure of charm jets is investigated by measuring jet shape variables and subjet multiplicities, as well as a specific angular distribution and its dependence on the jet energy, which might be expected to be sensitive to the suppression of soft gluons from heavy quarks close to their direction of flight. For such gluons the differential cross section can be approximated by [1]:

$$\frac{d\sigma_{Q\to Q+g}}{d\alpha} \approx K\frac{\alpha^3}{(\alpha_0^2+\alpha^2)^2}\,, \tag{1}$$

where

$$\alpha_0 = M_Q/E_Q\,, \tag{2}$$

with M_Q being the mass of the heavy quark and E_Q its energy. The angle between the radiated gluon and the primary heavy quark momentum is denoted by α. It follows from Eq. 1 that in the region of small α the emission of soft gluons is suppressed, and therefore this region is called the "dead cone". It is characterized by an opening angle α_0 which depends on the mass and energy of the heavy quark. Here an attempt is made to define an experimentally accessible angle which should approximate the parton level angle α.

Indirect evidence for the presence of the dead cone, based on comparing multiplicities in light-quark and heavy-quark jets has been reported by the DELPHI collaboration [2].

EXPERIMENTAL METHOD AND DATA SELECTION

At HERA, in ep collisions at $\sqrt{s} = 318$ GeV, the charm quarks are produced in DIS mainly via the boson-gluon fusion process [3]. They are produced in pairs and, in contrast to most e^+e^- experiments, close to the kinematic threshold. This allows to study the effect of the charm mass on jet structure at low jet momenta, in a region of phase space where these effects are expected to be measurable with the detector resolution of the H1 experiment. The data presented here were collected during the running periods of 1999 and 2000. A detailed description of the H1 detector is given in [4], and the components most relevant for this analysis are discussed in [3].

The scattered positron is detected in the backward calorimeter (SpaCal). In order to ensure high acceptance for the entire kinematic region, the square of the four momentum transfer[1] is restricted to $2 \leq Q^2 \leq 100$ GeV^2 and the inelasticity to $0.05 \leq y \leq 0.7$. The energy of the scattered positron is required to be larger than 8 GeV. In order to suppress background, cuts on the position of the event vertex ($|z_{\mathrm{vtx}}| < 35$ cm) and on the quantity $E - p_z$, summed over all hadronic particles and the scattered positron, ($40 < E - p_z < 75$ GeV) are applied.

The events with charm are tagged by reconstructing a D^*-meson[2] using the channel $D^{*+} \rightarrow D^0\pi_{\mathrm{s}}^+ \rightarrow K^-\pi^+\pi_{\mathrm{s}}^+$. As soon as a D^*-meson is found in an event, it is treated as one particle and its decay products are discarded. The range of the transverse momentum and the pseudorapidity[3] of the D^*-meson is restricted to $p_{\mathrm{t},D^*} > 1.5$ GeV and $|\eta_{D^*}| < 1.5$. Kinematic cuts, applied to individual charged particle tracks are: $p_{\mathrm{t},\pi_{\mathrm{s}}} > 0.12$ GeV, $p_{\mathrm{t},K,\pi} > 0.25$ GeV, $|\eta_{K,\pi,\pi_{\mathrm{s}}}| < 1.5$ and $p_{\mathrm{t},K} + p_{\mathrm{t},\pi} > 2$ GeV.

The D^*-signal is identified using the mass difference $\Delta m = m_{K\pi\pi_{\mathrm{s}}} - m_{K\pi}$ for a D^0-meson mass window $|m_{K\pi} - m_{D^0}| < 0.07$ GeV. The background is subtracted using the wrong-charge (WrCh)[4] events in the Δm range $0.143 < \Delta m < 0.148$ GeV. The normalization of the WrCh background is determined from a simultaneous fit to both the right-charge (RiCh) and WrCh Δm distributions.

Jets are found using the inclusive k_{t} cluster algorithm [5], applied in the laboratory frame, and events with at least one jet having $p_{\mathrm{t,jet}} > 1.5$ GeV and containing a D^*-meson are accepted. The properties of this jet, the D^*Jet, and of a second jet defined as the largest p_{t} jet not containing the reconstructed D^*-meson, the *Other*Jet[5], if observed within fiducial limits, are studied.

The observables used to study the energy flow inside a jet are the jet shape variables, averaged over all jets in data, defined as:

$$< \psi(r/R) >= \frac{1}{N_{\mathrm{jets}}} \sum_{\mathrm{jets}} \frac{E_{\mathrm{t,jet}}(r)}{E_{\mathrm{t,jet}}(r = R)}\ , < \rho(r/R) >= \frac{d\psi}{dr} = \frac{1}{N_{\mathrm{jets}}} \sum_{\mathrm{jets}} \frac{E_{\mathrm{t,jet}}(r, r + \Delta r)}{E_{\mathrm{t,jet}}(r = R)}\ , \quad (3)$$

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1 $Q^2 = 4E_eE'_e\cos^2\left(\frac{\theta_e}{2}\right)$; $y = 1 - \frac{E'_e}{E_e}\sin^2\left(\frac{\theta_e}{2}\right)$.

2 D^* refers to both D^{*+} and D^{*-} states.

3 Here and later in this paper η denotes the pseudorapidity of a particle: $\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$.

4 $D^{*+} \rightarrow K^+\pi^+\pi_{\mathrm{s}}^-$ and charge conjugate.

5 The azimuthal opening angle between the D^*Jet and the *Other*Jet shows the expected back-to-back topology in the γ^*p-frame, with a small tail extending to lower angles.

where $E_{\mathrm{t,jet}}(r)$ is the total transverse energy of particles inside a cone with the size $r = \sqrt{\Delta\phi^2 + \Delta\eta^2}$ around the jet axis, $E_{\mathrm{t,jet}}(r, r+\Delta r)$ is the total transverse energy of particles between a cone with size r and one with $r+\Delta r$. The radius R is set to one.

The mean subjet multiplicity is defined as the number of subjets inside the jet, found by the inclusive k_{t} jet finder as a function of the jet resolution parameter y_{cut}.

$$< n_{\mathrm{sbj}}(y_{\mathrm{cut}}) >= \frac{1}{N_{\mathrm{jets}}} \sum_{i=1}^{N_{\mathrm{jets}}} n^{i}_{\mathrm{sbj}}(y_{\mathrm{cut}}) \tag{4}$$

Fig. 1 shows that the observed distributions are well described by the RAPGAP 2.8/JETSET 7.4 MC model [6] predictions. The observables are shown at the detector level[6].

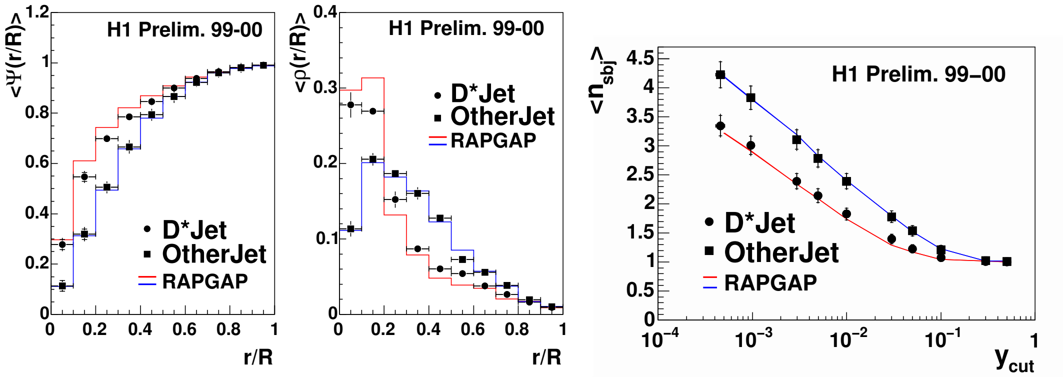

FIGURE 1. The jet shape variables compared to the QCD model for the D^*Jet and the $Other$Jet.

The method to approximate the angular distribution of the soft gluons with respect to the quark direction measures the "gluon" subjet angle, α, in different bins of $E_{D^*\mathrm{Jet}}$ and $E_{Other\mathrm{Jet}}$. The subjets are found by re-running the k_{t} algorithm on particles inside the D^*Jet and the $Other$Jet until two subjets are found. The "gluon" subjet angle α is defined as the angle between the direction of the D^*Jet ($Other$Jet) and the direction of the subjet not containing the D^*-meson (the less energetic subjet of the $Other$Jet).

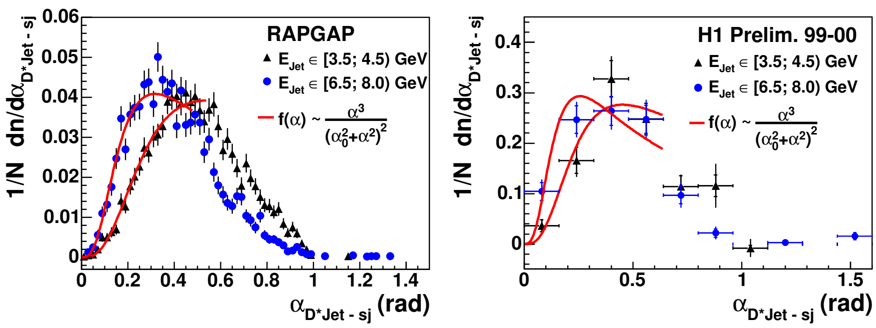

FIGURE 2. The distribution of the angle α between the "gluon" subjet and the D^*Jet for two bins in jet energy for data (right) and the QCD model RAPGAP/JETSET (left). The solid lines indicate the results of a fit using the function $f(\alpha) \sim \alpha^3/(\alpha_0^2+\alpha^2)^2$ predicted by the QCD theory.

[6] The α distributions have been calculated also at the parton and hadron level in the MC.

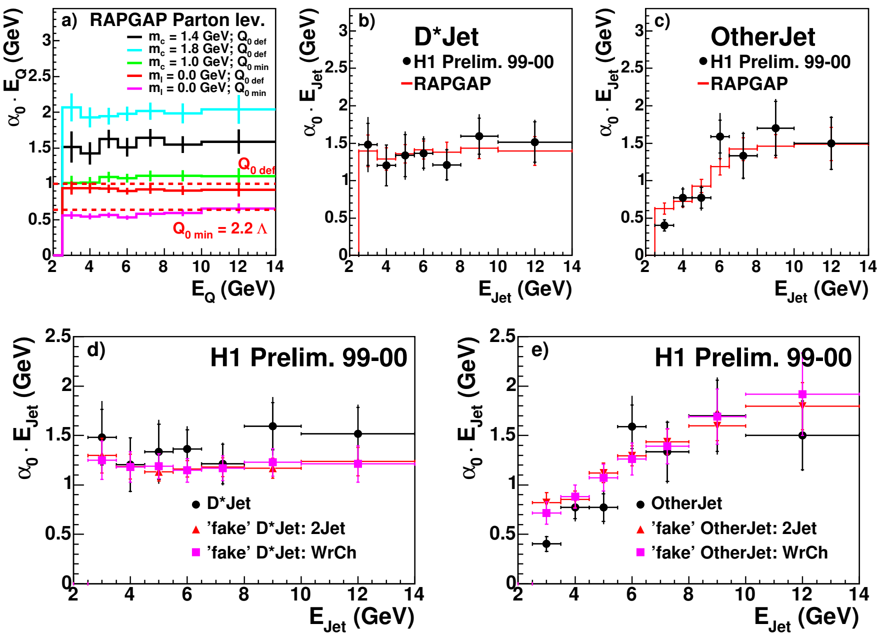

FIGURE 3. The $\alpha_0 E_{\mathrm{jet(Q)}}$ distributions. Q_0 is the invariant mass cut-off ($Q_{0\mathrm{def}} = 1$ GeV, $\Lambda = 0.29$ GeV).

In Fig. 2 one observes a shift of the α distribution to smaller angles with increasing $E_{D^*\mathrm{Jet}}$ as expected from Eq.1, which provides a reasonable fit at small angles to the data and MC. It allows to determine values for α_0 for different E_{jet}. From Eq. 2 one expects that the distribution $\alpha_0 \cdot E_{\mathrm{jet}}$ is independent of the E_{jet}, i. e. a constant of size M_Q. In Fig. 3a) the QCD model predictions, including the soft gluon suppression, are shown at parton level for different values of m_c, Q_0 and for $m_{l=u,d,s} = 0$. In Fig. 3b) and c) the distributions of $\alpha_0 E_{\mathrm{jet}}$ for the D^*Jet and the $Other$Jet are shown as a function of E_{jet}. They are well described by the QCD model predictions; a flat behavior is not expected for $E_{Other\mathrm{Jet}}$ below about 5 GeV due to a deteriorating reconstruction of the charm quark or even misidentifying it. In Fig. 3d) and e) the D^*Jet and $Other$Jet data are compared with "fake" D^*Jet: WrCh and 2Jet[7], respectively "fake" $Other$Jet.

The distributions look somewhat different from the ones from genuine charm jets but 'agree' within the errors[8]. Further studies and more statistics are needed to clarify these differences.

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[7] Both samples are dominated by light quarks WrCh($\sim 70\%$) and 2Jet($\sim 80\%$).
[8] The individual systematic errors have been added in quadrature.