SUBSTRUCTURE OF JETS AT HERA

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The substructure of jets produced in an exclusive and a charm-induced dijet sample in photoproduction and in charged and neutral current interactions has been studied with the ZEUS detector at HERA. Jets were identified using the longitudinally invariant k_T cluster algorithm in the laboratory frame. The substructure of jets has been studied in terms of the jet shape and subjet multiplicity. Comparisons between the dijet sample and the quark-induced samples allow an extraction of the jet substructure for gluons. Leading-logarithm parton-shower Monte Carlo calculations give a good description of the differences between quark- and gluon-initiated jets. In neutral current interactions, the measurements have been compared to next-to-leading-order QCD calculations which are used to make a determination of the strong coupling constant, α_s.

1 Introduction

The internal structure of jets gives insight into the transition between partons produced in the hard scattering process and the experimentally observable jets of hadrons. The substructure of jets is expected to depend mainly on the type of primary parton, quark or gluon, and to a lesser extent on the particular hard scattering process. QCD predicts that at high transverse energy of the jet, E_T^{jet}, where fragmentation effects become negligible, the jet structure is driven by gluon emission from the primary parton and gluon jets are broader than quark jets due to the larger colour charge of the gluon. The substructure of jets has been studied in terms of the integrated jet shape [1], $\Psi(r)$, and the differential jet shape [1], $\rho(r)$, where the energy flow inside a jet is considered, and the subjet multiplicity [2], $\langle n_{sbj}\rangle$, where jet-like structures (subjets) within a given jet are studied. The data samples used in these analyses were collected with the ZEUS detector at HERA. During 1995-1997 (1999-2000) HERA operated with positrons of energy $E_e = 27.5$ GeV colliding with protons of energy $E_p = 820$ GeV ($E_p = 920$ GeV).

2 Jet substructure in exclusive and charm-induced dijets in γp

Jet shapes and subjet multiplicities in exclusive and charm-induced dijet samples in photoproduction (PHP) for the kinematic region $Q^2 \leq 1$ GeV^2 and inelasticity $0.2 < y < 0.85$ have been measured. Dijets events were identified with the k_T-cluster algorithm [3] and selected with $E_T^{jet_{1,2}} \geq 7,6$ GeV and $-1 < \eta^{jet} < 2$. Charm quarks were tagged by identifying $D^{*\pm}$ mesons through the $K2\pi$ decay mode using the ΔM method . The jet with closest

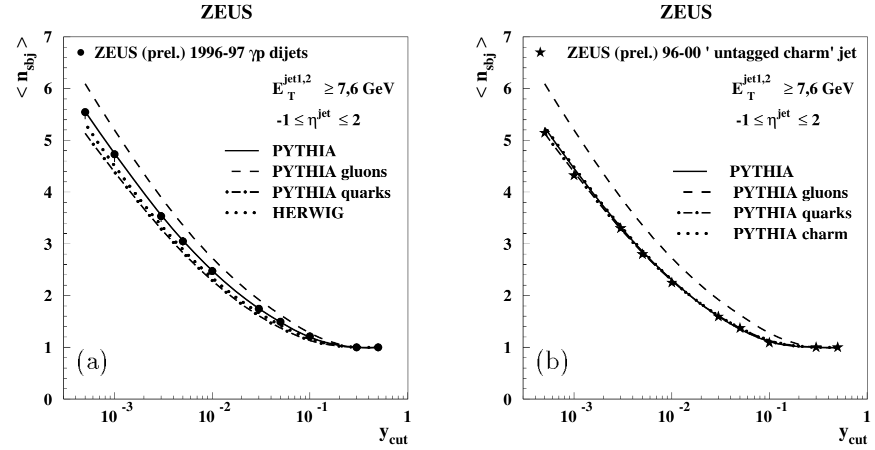

Figure 1. Measured $\langle n_{sbj} \rangle$ as a function of y_{cut} corrected to hadron level for (a) the exclusive dijet sample, and (b) the "untagged-charm" jet in photoproduction.

distance in azimuthal angle to the D^* meson was associated with the charm meson. The jet not associated with the D^*, referred to as the "untagged-charm" jet, represents the unbiased, i.e. not influenced by the D^* selection, jet candidate whose internal properties are studied.

The measured $\langle n_{sbj} \rangle$ as a function of the resolution scale, y_{cut}, for the exclusive dijet sample is shown in Fig. 1a. The predicted $\langle n_{sbj} \rangle$ is larger for gluon-initiated jets than for quark-initiated jets and the measured data are located between the two curves, showing that the dijet sample is a mixture of quark and gluon jets. PYTHIA [4] gives a good description of the data. Fig. 1b shows $\langle n_{sbj} \rangle$ as a function of y_{cut} for the "untagged-charm" jet. The agreement between data and theory is very good and the predictions of charm-initiated jets are consistent with the measurements.

The dependence of the substructure of jets with η^{jet} has also been studied. In the exclusive dijet sample, $\langle n_{sbj} \rangle$ increases with η^{jet} (Fig. 2a), which is

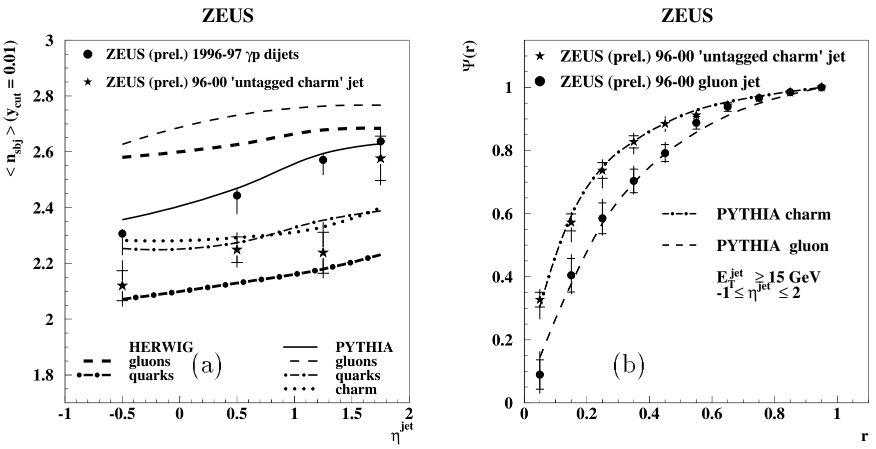

Figure 2. (a) $\langle n_{sbj} \rangle$ at a fixed $y_{cut} = 0.01$ as a function of η^{jet} corrected to hadron level for the exclusive dijet sample and the "untagged-charm" jet . (b) Integrated jet shape of the measured "untagged-charm" jet and the extracted gluon jet substructure.

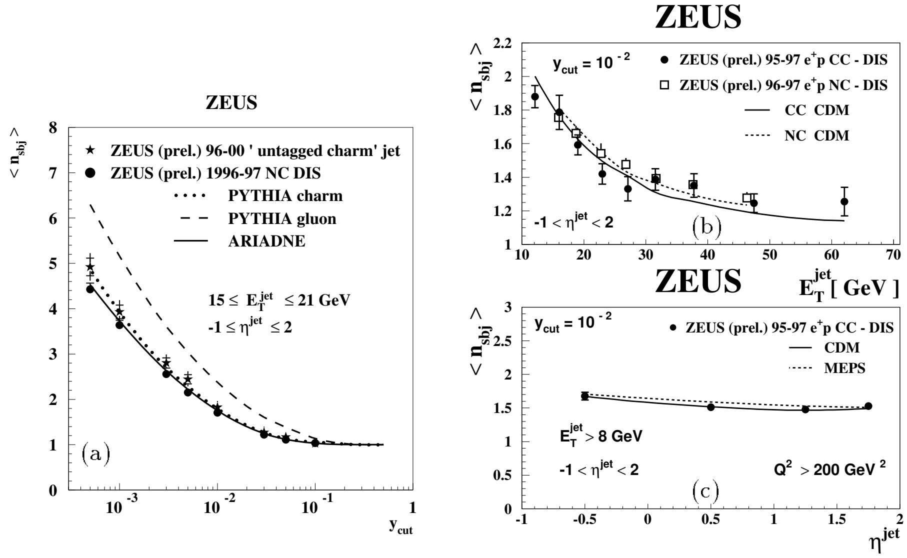

Figure 3. (a) Comparison of the subjet multiplicity as a function of y_{cut} corrected to hadron level for the "untagged-charm" jet PHP sample and inclusive jet production in NC DIS . (b) Comparison of $\langle n_{sbj}\rangle$ for a fixed $y_{cut} = 0.01$ as a function of E_T^{jet} for inclusive jet production in NC and CC DIS. (c) Dependence of $\langle n_{sbj}\rangle$ with η^{jet} for a fixed $y_{cut} = 0.01$ in CC DIS.

consistent with the predicted increase in the fraction of gluon-initiated jets with η^{jet}. In the "untagged-charm" jet sample, the results are consistent with a pure sample of quark jets for $-1 < \eta^{jet} < 1.5$. For the highest η^{jet} values, the data show a deviation from the prediction for quark-induced jets. Since the estimated gluon contamination to the charm-induced jet sample (mainly due to "charm excitation") has its highest contribution in the forward region, the deviation could be explained by the increase of the gluon-jet fraction in the charm-enriched sample.

Since the dijet PHP sample consists of a mixture of quark and gluon jets, any measured observable $\mathcal{O}$ of the internal structure can be written as: $\mathcal{O}_{dijet} = f_q \cdot \mathcal{O}_{quark} + f_g \cdot \mathcal{O}_{gluon}$, where f_q, $f_g = 1 - f_q$ are the fractions of quark and gluon jets. The measurements of the substructure of the charm-enriched sample at high transverse energies ($E_T^{jet} > 15$ GeV) can be considered as measurements for a pure sample of quark jets ($\mathcal{O}_{charm} = \mathcal{O}_{quark}$). Taking the fractions f_q, f_g from LO Monte Carlo, the substructure of gluon jets can be extracted. The fraction f_q predicted for a dijet sample with $E_T^{jet} > 15$ GeV and $-1 < \eta^{jet} < 2$ by PYTHIA ($f_q = 0.66$) and HERWIG [5]($f_q = 0.69$) are found to be similar. Fig. 2b shows the extracted gluon jet substructure, which is consistent with the QCD predictions.

3 Jet substructure in deep inelastic scattering

Quark initiated jets are expected to be predominant in charged current (CC) and neutral current (NC) deep inelastic scattering (DIS). In Fig. 3a, $\langle n_{sbj}\rangle$ as a function of y_{cut} in the "untagged-charm jet" PHP sample and an inclusive jet NC sample ($Q^2 > 125$ GeV^2) are compared. The measurements are found

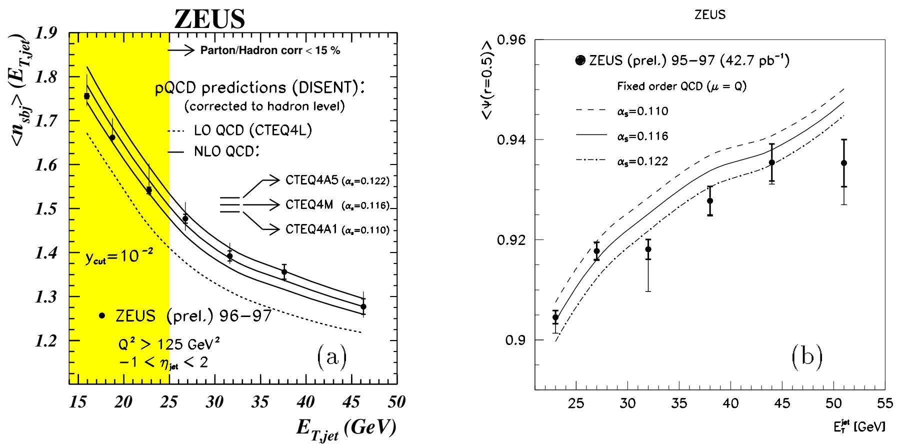

Figure 4. Measured (a) $\langle n_{sbj}\rangle$ and (b) $\langle\Psi(r)\rangle$ for a fixed $y_{cut} = 0.01$ as function of E_T^{jet}. The data are compared to NLO QCD calculations for different values of α_S.

to be similar and in very good agreement for resolution scales $y_{cut} > 0.01$, where the charm mass effects are negligible. The charm-initiated jets are very similar to light quark jets. Fig. 3b shows the evolution of $\langle n_{sbj}\rangle$ with E_T^{jet} for a fixed $y_{cut} = 0.01$ in NC and CC processes. The value of $\langle n_{sbj}\rangle$ decreases as E_T^{jet} increases. The agreement between both measurements indicates that the pattern of parton radiation within quark jets is to a large extent independent of the hard scattering process. In Fig. 3c $\langle n_{sbj}\rangle$ for a fixed $y_{cut} = 0.01$ as a function of η^{jet} in CC interactions ($Q^2 > 200$ GeV^2) is shown. Both ARIADNE (CDM) [6] and LEPTO (MEPS) [7] give a good description of the data. The substructure in DIS processes shows no dependence with η^{jet}.

In NC processes, the subjet multiplicity (Fig. 4a) as a function of E_T^{jet} for a fixed $y_{cut} = 0.01$ and the mean integrated jet shape (Fig. 4b) for a fixed radius of $r = 0.5$ have been compared to NLO QCD predictions and α_S has been determined. The extracted value from $\langle n_{sbj}\rangle$ for jets with $E_T^{jet} > 25$ GeV is $\alpha_S(M_Z) = 0.1185 \pm 0.0016(stat)^{+0.0067}_{-0.0048}(exp)^{+0.0089}_{-0.0071}(th)$.

The extracted value from $\langle\Psi(r)\rangle$ for jets with $E_T^{jet} > 21$ GeV is
$\alpha_S(M_Z) = 0.1179 \pm 0.0017(stat)^{+0.0054}_{-0.0065}(exp)^{+0.0094}_{-0.0073}(th)$.

Both values are in good agreement with the world average value [8].

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