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DETERMINATION OF THE STRONG COUPLING CONSTANT USING SUBJET MULTIPLICITIES IN NEUTRAL CURRENT DEEP INELASTIC SCATTERING

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The internal structure of the jets produced in neutral current interactions for $Q^2 > 125$ GeV^2 has been studied using the subjet multiplicity with the ZEUS detector at HERA. Jets are identified in the laboratory frame by applying the longitudinally invariant k_T-cluster algorithm. Next-to-leading order QCD calculations have been obtained and compared to the data; a good agreement has been observed in the region where hadron-to-parton corrections are small, $E_{T,jet} > 25$ GeV. In this region, the strong coupling constant is extracted and the resulting value is $\alpha_s(M_Z) = 0.1185 \pm 0.0016$ (stat.)$^{+0.0067}_{-0.0048}$ (syst.)$^{+0.0089}_{-0.0071}$ (th.).

1 Introduction

The study of the internal structure of jets gives insight into the transition between partons produced in a hard process and the experimentally observable spray of hadrons. This type of analysis is usually made using jet shapes[1], where the energy flow inside the jet is considered, or the subjet multiplicity[2], where the study is done with jet-like structures (subjets) within a given jet. These structures are called subjets and are formally defined as the original jets, but resolved at a smaller scale. At sufficiently high jet energy, where fragmentation effects are small, the internal structure of the jets is expected to depend mainly on the parton-radiation pattern and should be calculable in pertubative QCD.

Studies of the internal structure of jets have been made in $p\bar{p}$ collisions at Tevatron[3] and in e^+e^- interactions at LEP[4]. It has been observed that phenomenological models for the parton radiation based on QCD give a good description of the data. In addition, the results are in agreement with the expectation that the internal structure is determined by the type of the primary parton. It is observed that gluon-initiated jets are broader (i.e. contain a larger number of subjets) than quark-initiated jets, as predicted by QCD from the larger color charge of the gluon. At HERA, measurements of subjet multiplicities have previously been presented in quasi-real photon proton collisions (photoproduction)[5] and in neutral current deep inelastic scattering[6]. In photoproduction, the mean subjet multiplicity ($< n_{sbj} >$) is observed to become larger as the jet pseudorapidity (η_{jet}) increases, in agreement with the predicted increase in the fraction of gluon-initiated jets. In deep inelastic scattering for jets defined in the Breit frame, it has been observed that jets pcontain a smaller number of subjets with increasing transverse energies and towards the forward region of the Breit frame.

New measurements of the mean subjet multiplicity for jets produced in neutral current deep inelastic scattering with the ZEUS detector at HERA are presented here. The jets are selected using the longitudinally invariant k_T-cluster algorithm[7] in the laboratory frame. Next-to-leading order (NLO) QCD calculations for $< n_{sbj} >$ are now available for jets defined in this frame and they are compared to the data after hadronization corrections are applied. From this comparison, the value of the strong coupling constant is extracted.

2 Measurement of the mean subjet multiplicity

The data sample used in this analysis was collected with the ZEUS detector at HERA and corresponds to an integrated luminosity of 38 pb^{-1}. During 1996-1997, HERA operated with positrons of energy $E_e = 27.5$ GeV colliding with protons of energy $E_p = 820$ GeV. Neutral current events were selected by requiring a positron candidate identified in the main calorimeter (UCAL). After removing the background contributions, events with $Q^2 > 125$ GeV^2 were kept and the jet algorithm was applied to the UCAL cells belonging to the hadronic system. The jet search is performed in the pseudorapidity (η) [a] - azimuth (ϕ) plane of the laboratory frame. The jet variables are defined according to the Snowmass convention[8]. The inclusive sample of jets with transverse energy $E_{T,jet} > 15$ GeV and $-1 < \eta_{jet} < 2$ has been studied.

For each jet in the sample, the jet algorithm was re-applied to all the particles assigned to the given jet. The clustering was stopped when the distances y_{ij} between all pair of particles i, j are above some resolution scale y_{cut}

$$y_{ij} = \frac{min\{E_{T,i}, E_{T,j}\}^2}{E_{T,jet}^2} \left(\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2\right) > y_{cut}.$$

All clusters found in this way are called subjets.

The quantity $\sqrt{y_{cut}} E_{T,jet}$ determines the scale at which the internal structure of the jet is resolved. If this quantity is large, then the subjet structure is given by parton-radiation processes in which the relative transverse momentum is hard enough and perturbative QCD should be applicable to describe the subjet structure of the jets.

The mean subjet multiplicity is defined as the average of the number of subjets in the considered sample of jets at a given y_{cut}. The mean subjet multiplicity has been studied as a function of y_{cut} and of the jet variables for a fixed $y_{cut} = 0.01$.

A simulation of the detailed properties of the hadronic final state is available in various Monte Carlo event generators. The generated samples of events have been passed through a detector simulation and analysed by the same program chain as the data. The response of the detector to jets of hadrons and the correction

[a] The pseudorapidity is defined as $\eta = -\ln(\tan(\theta/2))$ where θ is the polar angle with respect to the proton beam direction.

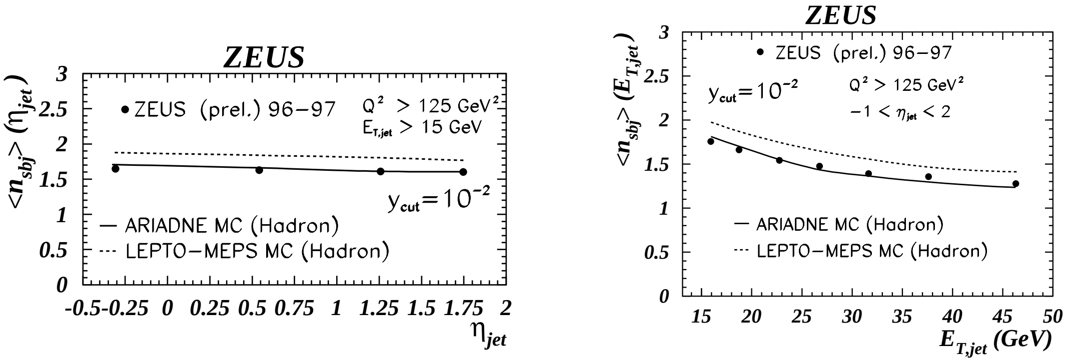

Figure 1. Measured mean subjet multiplicity corrected to hadron level for jets produced in neutral current DIS interactions as a function (left) of the jet pseudorapidity and (right) of the jet transverse energy in the laboratory frame.

factors for $< n_{sbj} >$ have been determined by applying the same jet algorithm to the hadron level of the simulated events.

Figure 1 shows the measurements of the mean subjet multiplicity as a function of the jet pseudorapidity and jet transverse energy for $y_{cut} = 0.01$. The data have been corrected to the hadron level and compared to the predictions of two Monte Carlo models. The color-dipole model as implemented in ARIADNE[9] gives a very good description of the data while the matrix element plus parton shower (MEPS) model of LEPTO[10] is above the data.

It is observed that the mean subjet multiplicity has no η_{jet} dependence. This is different than the results observed in photoproduction[5], where an increase is observed as η_{jet} increases. These two different behaviors can be understood in terms of the admixtures of quark- and gluon-initiated jets in the two reactions. In the analysis of neutral current deep inelastic scattering presented here, the observed distribution is consistent with the expectation that the sample is dominated by quark-initiated jets from the Born process for the entire η_{jet} range. Comparisons with the predictions by the Monte Carlo models for quark- and gluon-initiated jets confirm this explanation.

On the other hand, the mean subjet multiplicity is observed to decrease as the transverse energy of the jets increases. This means that the jets become narrower as $E_{T,jet}$ increases, in agreement with the expectations. A similar behavior has been observed in previous results at HERA, Tevatron and LEP by using subjet multiplicities or jet shapes.

3 NLO QCD calculations

For jets defined in the laboratory frame, it is possible to obtain predictions for the mean subjet multiplicity from perturbative QCD to the second order in α_s. The perturbative QCD calculations have been obtained with the program DISENT[11]. The number of flavors was set to 5 and the renormalization (μ_R) and factoriza-

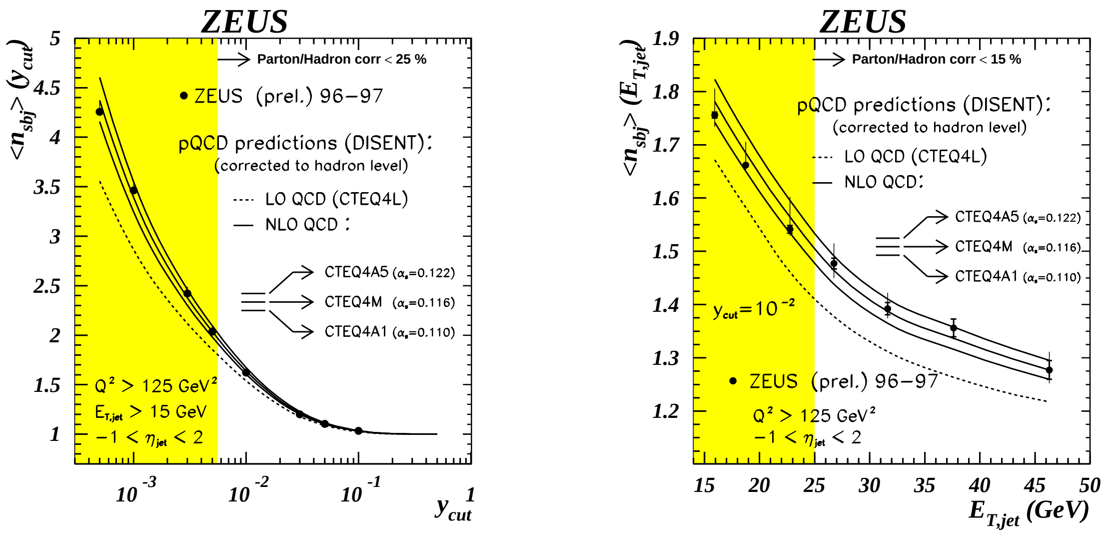

Figure 2. Measured mean subjet multiplicity corrected to hadron level for jets produced in neutral current DIS interactions. The data are compared to NLO QCD calculations for different values of α_s: (left plot) $< n_{sbj} >$ as a function of y_{cut}; (right plot) $< n_{sbj} >$ at $y_{cut} = 0.01$ as a function of the transverse energy of the jets in the laboratory frame.

tion (μ_F) scales were both set to Q. The main source of theoretical uncertainty is due to terms beyond NLO and has been estimated by varying μ_R between $Q/2$ and $2\,Q$, keeping μ_F fixed at Q.

To compare with the data, the predictions given by DISENT (at parton level) have been corrected for hadronization effects by using the Monte Carlo models. In the ARIADNE and LEPTO models, the hadronization is performed by using the LUND string model[12] as implemented in JETSET[13].

The perturbative QCD predictions corrected for hadronization effects are compared to the data in figure 2. The predictions give a good description of the data, even where parton-to-hadron corrections are large. NLO QCD predictions have been obtained for different values of α_s. The parametrizations of the proton parton distribution functions assuming different values of $\alpha_s(M_Z)$ as given in the CTEQ4A-series[14] have been used; this procedure takes into account the correlations between the value of $\alpha_s(M_Z)$ used in the matrix elements and that assumed in the parametrization of the parton distribution functions.

The comparison of the data with the theoretical predictions for different values of α_s shows that the measurements are sensitive to $\alpha_s(M_Z)$.

4 Determination of α_s

The value of α_s has been extracted in the region where parton-to-hadron corrections are below 15%. The method consists of making a parametrization of the dependence on α_s of the theoretical predictions for the mean subjet multiplicity. A preliminary study of the systematic uncertainties has been performed; the most important contribution is the uncertainty on the modelling of the hadronic final state.

The extracted value of $\alpha_s(M_Z)$ using $< n_{sbj} >$ at $y_{cut} = 0.01$ and for jets with $E_{T,jet} > 25$ GeV is

$$\alpha_s(M_Z) = 0.1185 \pm 0.0016 \text{ (stat.)}^{+0.0067}_{-0.0048} \text{ (syst.)}^{+0.0089}_{-0.0071} \text{ (th.)}$$

in good agreement with the world average value[15].

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