MEASUREMENT OF EVENT SHAPE VARIABLES IN DEEP-INELASTIC SCATTERING AT HERA

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Deep-inelastic *ep* scattering data taken with the H1 detector are used to study the differential distributions of event shape variables. The event shape distributions are compared with QCD predictions, and are consistent with a universal "effective non-perturbative coupling" $\alpha_0 \approx 0.5$

The event shapes (ES) is a specific class of QCD observables that can tell us something about genuine non-perturbative effects in multiple production of hadrons in hard processes. The ES measure global properties of final states (jet topologies) in an inclusive manner. Like jet observables ES are constructed to be collinear and infrared safe (CIS) but no hard scale is attached to them. For this reason ES probe deep into non-perturbative region and are particularly valuable as a test for Power Corrections (PC) technique. Predictive power of the PC phenomenology [1], [2] depends on the degree of universality (i.e independence of observable, scale, process etc.) of its single free parameter namely the effective non-perturbative coupling α_0. The analyses of mean values and distributions of ES variables measured in e^+e^- experiments at LEP [6,7,8] and DIS experiments at HERA [4] [5] provided a support for notion of α_0 universality. Higher-order corrections have since become available in the form of soft gluon re-summed calculations matched to NLO matrix elements [9]. This put the study of ES distributions and of the interplay between perturbative and non-perturbative QCD in the description of the hadronic final state on a new quantitative level. Here we present recent results of the H1 Collaboration [10], in which QCD analysis is based on up-to-date theory.

The event shape variables may be distinguished according to the event axis used. The definitions of *Thrust* $\tau = 1 - T$, $T = \sum_h |\vec{p}_{z,h}|/\sum_h |\vec{p}_h|$ and *Jet Broadening* $B = \sum_h |\vec{p}_{t,h}|/2\sum_h |\vec{p}_h|$ employ momentum vectors projected onto the exchanged boson direction, the others do not, like their counterparts in e^+e^-: τ_C calculates the *Thrust* with respect to the direction which maximizes the sum of the longitudinal momenta of all particles in the current hemisphere, the squared *Jet Mass* $\rho = (\sum_h E_h)^2 - (\sum_h \vec{p}_h)^2)/(2\sum_h |\vec{p}_h|)^2$ and the *C-Parameter* which is defined as $C = 3/2 \times \sum_{h,h'} |\vec{p}_h||\vec{p}_{h'}|\cos^2\theta_{hh'}/(\sum_h |\vec{p}_h|)^2)$ where $\theta_{hh'}$ is the angle between particles h and h'. In all the definitions above the momenta are defined in the Breit frame and the sums extend over all particles in the current hemisphere. Explicit use of the boson direction implies sensitivity to radiation into the remnant hemisphere through recoil effects on the current quark [9]. For ES analysis we used inclusive

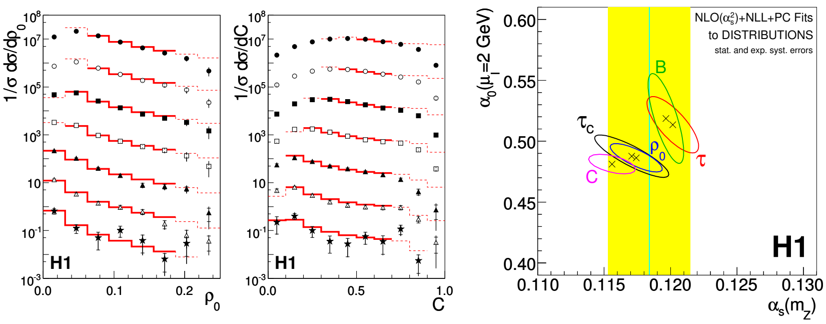

Figure 1. **LEFT:** Normalized event shape distributions corrected to the hadron level for ρ_0 and the C-parameter. The solid lines represent fit results, the dashed lines - fit extrapolations. $\langle Q\rangle = 15(\mathit{top}), 18, 24, 37, 58, 81, 116(\mathit{bottom})$ GeV scaled by factors 20^n. **RIGHT:** Fit results to the differential distributions of τ, B, ρ_0, τ_C and the C-parameter in the (α_s, α_0) plane.

high Q^2 NC DIS selection representing 106 pb^{-1}. In the phase space $196 < Q^2 < 40,000$ GeV^2, $0.1 <$y< 0.8 our sample reaches almost 108,000 events , allowing for relatively narrow binning both in Q (7 bins) and 8-10 bins in ES variables, in total 322 bins. Corrections to hadron level were made with the help of RAPGAP 2.8 in two steps: for limited detector resolution by Bayes unfolding, then for limited detector acceptance and QED effects using the bin-to-bin method. As an example we show event shape distributions at the hadron level for jet mass and the C-parameter in Figs. 1(left) over a wide range of $\langle Q\rangle = 15 - 116$ GeV. It should be noted that except for the highest Q bins, the precision of the measurements is not statistically limited. The distributions were compared with QCD calculations which contain a perturbative part (pQCD) dealing with partons and in addition use power corrections (PC) to describe the hadronisation. The perturbative part is made up of two contributions: fixed order terms calculated to next-to-leading order (NLO) in the strong coupling constant and re-summed terms in the next-to-leading-logarithmic (NLL) approximation.The fixed order coefficients are determined here using DISASTER++ [11] together with DISPATCH [9]. The re-summation has been performed by Dasgupta and Salam [9,12] and is available in the DISRESUM package, the modified logR matching scheme was chosen.

For the differential distributions the power correction results in a shift of the perturbatively calculated distribution [3] of ES variable. Its analytic form (assumed to be universal for all ES) is known at the two-loop level [14], and contains only two free parameters of the QCD theory of ES :α_0 and $\alpha_s(m_Z)$. It should be noted however that theory is not valid over the whole spectrum. For these reasons not all data points enter the QCD fit as seen in Fig. 1(left). In general the data are very well described by pQCD + PC theory. At low Q values the agreement between measurements and calculation degrades. In this domain the hadronisation effects become more important and simple shift of pQCD distributions is not expected to hold. Fit results to the differential distributions of τ, B, ρ_0, τ_C and the C-parameter in the (α_s, α_0) plane are shown in Fig. 1 (right). The quality of the fits, expressed in terms of χ^2 per degree of freedom, is found to be reasonable. For all event shape variables, consistent values for $\alpha_s(m_Z)$ and α_0 are found, with a maximum difference of about two standard deviations between τ and C. The values of the strong coupling $\alpha_s(m_Z)$ are in good agreement with the world average, shown for comparison as the shaded band. The non-perturbative parameter $\alpha_0 \simeq 0.5$ is confirmed to be universal within 10%. It should be noted, that the consistency between values of $\alpha_s(m_Z)$ and α_0 within groups of ES with and without reference to exchanged boson axis is excellent, while two standard deviations distance happens to divide ES from different ES groups. This indicates that quark recoil effects still play a significant role, and higher order pQCD calculations might improve the results. The good agreement of the results for all event shape variables allows a common set of values of $\alpha_s(m_Z)$ and α_0 to be derived by applying an averaging procedure to the results from the individual event shape variables. In this procedure, the χ^2 minimization takes into account all experimental and theoretical errors and the correlations between $\alpha(m_Z)$ and α_0. In addition the correlations among the observables are considered. The averaging procedure results in: $\alpha_s(m_Z) = 0.1198 \pm 0.0013\,(\mathrm{exp})\ ^{+0.0056}_{-0.0043}\,(\mathrm{theo}), \alpha_0 = 0.476 \pm 0.008\,(\mathrm{exp})\ ^{+0.018}_{-0.059}\,(\mathrm{theo})$, with a fit quality of χ^2/d.o.f. = 4.9/2. Here the theoretical error is derived from the renormalization scale uncertainty.

Having established the validity of the power corrections we can investigate the scale dependence of the strong coupling $\alpha_s(Q)$. For each ES variable a Q independent α_0 parameter and an $\alpha_s(Q)$ for each Q bin are fitted. The results of fits for the different ES variables are compatible with each other and may be combined. A fit of the renormalization group equation to the measured $\alpha_s(Q)$ yields $\alpha_s(m_Z) = 0.1178 \pm 0.0015$ (exp) ${}^{+0.0081}_{-0.0061}$ (theo), with $\chi^2/\mathrm{ndf} = 8.3/6$.

The mean values of the ES variables, were also subjected to QCD fits. For this application the re-summed calculation can not be used, hence the theoretical prediction for the mean values is solely based on a NLO calculation, supplemented by power corrections. The fitted values for $\alpha_s(m_Z)$ exhibit a rather large spread. Apparently theoretical description of mean values is not so good as in the case of distributions, likely due to lack of re-summation terms.

Summarising: Re-summed perturbative QCD predictions together with power corrections give good descriptions of the spectra of the ES observables, the parameter α_0, which accounts for hadronisation, is consistently found to be 0.5 within 10%.The observed universality of α_0 supports the concept of power corrections, finally, the running of $\alpha_s(Q)$ is clearly observed for each event shape variable, in accordance with the expected evolution.

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