Study of Mean Charged Multiplicity and Event Shapes using ZEUS detector at HERA

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Abstract

The hadronic final state has been investigated in inclusive neutral current deep inelastic scattering (DIS) with the ZEUS detector at HERA. The mean charged multiplicity observed for inclusive DIS events in the pseudorapidity region $|\eta_{\rm lab}| \leq 1.75$ has been measured. The results are compared to hadron-hadron and e^+e^- data. The topology of the hadronic final state has been investigated using event shape variables in the current region of the Breit frame.

1 Introduction

The study of hadronization and correlations between final-state particles at HERA is an important testing ground for QCD and may serve as a rich source of information about phenomenological aspects of the hadronization. Comparison of the mean charged multiplicities and event shapes in *ep* collisions to e^+e^- and *pp* results provide a unique opportunity to test the universal features of the hadronization and correspondent theoretical predictions over a large range of the four-momentum transfer squared, Q^2, the virtuality of the photon.

2 Measurements of mean charged multiplicity

The measurements of multiplicities of charged particles at colliders have yielded insights into hadronization mechanisms. It has been found that charged particle multiplicities measured as a function of the centre-of-mass (cms) energy, $\sqrt{s}$, at e^+e^- [1, 2] colliders are the same as those measured at *pp* [3, 4] colliders as a function of $\sqrt{q_{\rm tot}^{\rm had}} = \sqrt{[(q_1^{\rm inc} - q_1^{\rm leading}) + (q_2^{\rm inc} - q_2^{\rm leading})]^2}$, where $q_{1,2}^{\rm inc}$ and $q_{1,2}^{\rm leading}$ are the four-momenta of the incoming protons and leading particles that escape down the beampipe, respectively. It is therefore interesting to study charged particle multiplicities in *ep* collisions. The charged particle multiplicities have been investigated in both the laboratory and the Breit frames. The current region of the Breit frame is analogous to a single hemisphere of e^+e^- annihilation. In $e^+e^- \rightarrow q\bar{q}$ the two quarks are produced with equal and opposite momenta, $\pm\sqrt{s_{ee}}/2$. The fragmentation of these quarks can be compared to that of the quark struck from the proton. This quark has an outgoing momentum $-Q/2$ in the Breit frame. Therefore, two times the multiplicity of the current region of the Breit frame is expected to have a dependence on Q similar to that of the total multiplicity in e^+e^- annihilation versus the energy $\sqrt{s_{ee}} = Q$. To take into account contributions from soft and hard QCD processes that lead to a decrease of the energy and the number of particles in the current region of the Breit frame, $E_{\rm current}$ was used instead of $Q/2$, where $E_{\rm current}$ is the energy of all the particles in the current region of the Breit frame.

Figure 1 shows twice the measured mean charged multiplicity, $2\langle n_{\rm ch}\rangle$, in the current region of the Breit frame plotted versus $2E_{\rm current}$. Also shown are the prediction of Ariadne and the measurements from e^+e^- and hadron-hadron (*pp*) experiments together with a previous ZEUS measurement [5] where $2\langle n_{ch}\rangle$ was measured as a function of Q. Both ZEUS measurements agree with the e^+e^- measurement for values of energy above 10 GeV. At low values of energy, the measurement of the mean charged multiplicity as a function of $2E_{\rm current}$ agrees better with e^+e^-, since the migrations of final state particles out of the current region are properly taken into account in $E_{\rm current}$.

Similarly to $\sqrt{s}$, $2E_{\rm current}$ constitutes not only the energy but also the invariant mass of the system. It is natural to use the invariant mass as a scale for comparison of the mean charged multiplicities in the current and target region of the Breit frame. However, while almost 95% of the hadronic system of the current region is measured in the ZEUS detector, only $\sim 25\%$ is detected in the case of the target region. The measurement here is performed for the visible charged multiplicity as a function of the visible invariant mass $M_{\rm eff}$, which was reconstructed from the energy and momenta of the hadrons as:

$$M_{\rm eff}^2 = (\sum_i E_i)^2 - (\sum_i P_{X_i})^2 - (\sum_i P_{Y_i})^2 - (\sum_i P_{Z_i})^2 \ , \tag{1}$$

where the sum runs over the calorimeter energy flow objects (EFOs) [6] in a pseudorapidity range $|\eta_{\rm lab}| < 1.75$; or hadrons of the system, in the case of hadron level MC.

Figure 2 (left) shows the measured $\langle n_{\rm ch} \rangle$ for the visible part of the current and target regions of the Breit frame versus $M_{\rm eff}$. The measurement shows approximately the same number of particles produced for the same $M_{\rm eff}$ in the visible part of the current and target regions. Because of the energy restrictions, the highest achievable $M_{\rm eff}$ in the current region is smaller than that for the target region. The predictions for each region of the Breit frame are also shown. ARIADNE describes the measurements for both the current and target regions of the Breit frame.

Since both the number of particles and $M_{\rm eff}$ are boost invariant, the study of the total visible multiplicities is continued in the laboratory frame. Thus the laboratory frame measurement (combined current+target) is already shown in figure 2 (left) as solid circles. A study of $\langle n_{\rm ch} \rangle$ as a function of $M_{\rm eff}$ in the laboratory frame for different x regions together with predictions from ARIADNE is shown in figure 2 (right). A weak x dependence is observed both in data and MC. Comparing figure 2 with figure 1 one can see about 15% difference in the mean charged multiplicity between ep and e^+e^- (and pp) data for the same invariant mass. This observation is currently being investigated. The ARIADNEin general describes the data, while LEPTO and LEPTO SCI which includes soft color interactions are above the data (not shown). Similar behavior of ARIADNE and LEPTO has been observed in previous measurements [5].

3 Event shape measurements

The event shapes studied at ZEUS [7] are thrust T, broadening B, jet mass M, and the C-parameter C. The measurements were performed in the kinematic range $80 < Q^2 < 2 \cdot 10^4\ {\rm GeV}^2$ and $0.0024 < x < 0.6$ in the current region of the Breit frame, in order to facilitate comparison with e^+e^- experiments [8].

According to the theoretical model of power corrections (PC) introduced by Y. Dokshitzer and B. Webber [9], event-shape values, $\langle F \rangle$, can be described as the sum of perturbative, $\langle F \rangle_{\rm pert}$, and non-perturbative , $\langle F \rangle_{\rm PC}$, terms. The perturbative contribution is then calculated using QCD next-to-leading-order (NLO) programs such as DISENT [10] and DISASTER [11], while the non-perturbative term is an analytical function of two parameters $(\alpha_s, \overline{\alpha_0})$, where $\overline{\alpha_0}$ is an effective coupling. By fitting the measured Q^2 dependence of the mean event-shape values to the NLO + PC prediction, values for α_s and $\overline{\alpha_0}$ were extracted.

The extraction of α_s and $\overline{\alpha_0}$ from each mean event-shape value provided values of α_s and $\overline{\alpha_0}$ that are consistent overall with each other and with the world average. Figure 3 shows the extracted values $(\alpha_s, \overline{\alpha_0})$ for each event-shape mean studied. There is a spread between most of the values and with the values extracted from thrust with respect to the photon axis in the Breit frame and broadening with respect to the thrust axis in the Breit frame.

The dispersion of the α_s and $\overline{\alpha_0}$ values could be due to higher-order terms that are not present in the NLO + PC calculations. Studying the differential event-shape distributions provides a way to analyze the effects of those higher-order terms. Due to the lack of convergence of the perturbative series for the differential distributions, the NLO + PC model used for the mean is not expected to describe the distributions. To study the event-shape distributions, a resummation [12] of the next-to-leading logarithm (NLL) is required. The effect of adding the PC terms to the NLO + NLL prediction causes a shift in the distributions.

Power-correction theory is not expected to be accurate in all regions of the event shape distributions because the lack of terms beyond NLO in the perturbative series causes a deficit of very broad events and an excess of strongly collimated events. Therefore, the predictions do not match the data at each end of the distributions. By studying the differential distributions, one can identify regions in phase space where the model is performing well, and restrict the fits to these regions. The missing higher-order, resummation terms still make small, but significant, contributions, even in this restricted phase space.

H1 and ZEUS have recently made measurements [8] of the differential distributions. As described above, the NLO + NLL + PC predictions are fit to the measurements in a restricted range. The NLO + NLL + PC predictions are shown together with the measured distributions in figure 4, for the thrust distribution.

Based on the fits to the event-shape distributions, values for α_s and $\overline{\alpha_0}$ are extracted from each event shape. As with the values extracted from the measurement of the means, the values extracted from the measured distributions provide consistent values for α_s (see figure 5).The values extracted for $\overline{\alpha_0}$ are a little lower than for other experiments, most notably the value from C-parameter.

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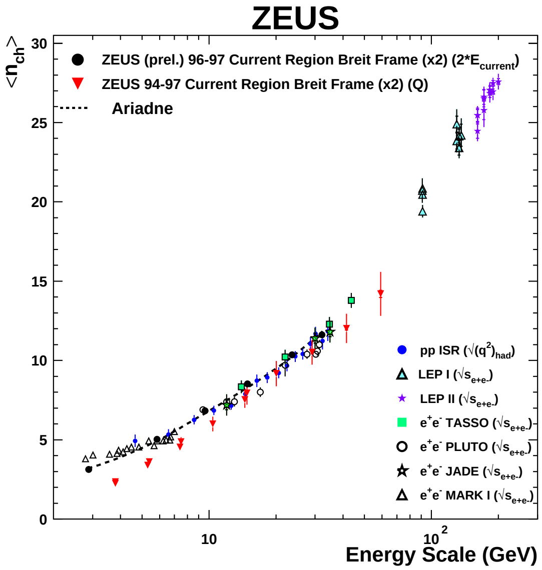

Figure 1: Mean charged multiplicity, $\langle n_{\rm ch}\rangle$, in the current region of the Breit frame multiplied by 2 plotted versus $2E_{\rm current}$, where $E_{\rm current}$ is the sum of the energies of the particles in the current region (charged hadrons and neutrals). Also shown are the prediction from ARIADNE and other measurements from hadron-hadron, e^+e^-, and ep.

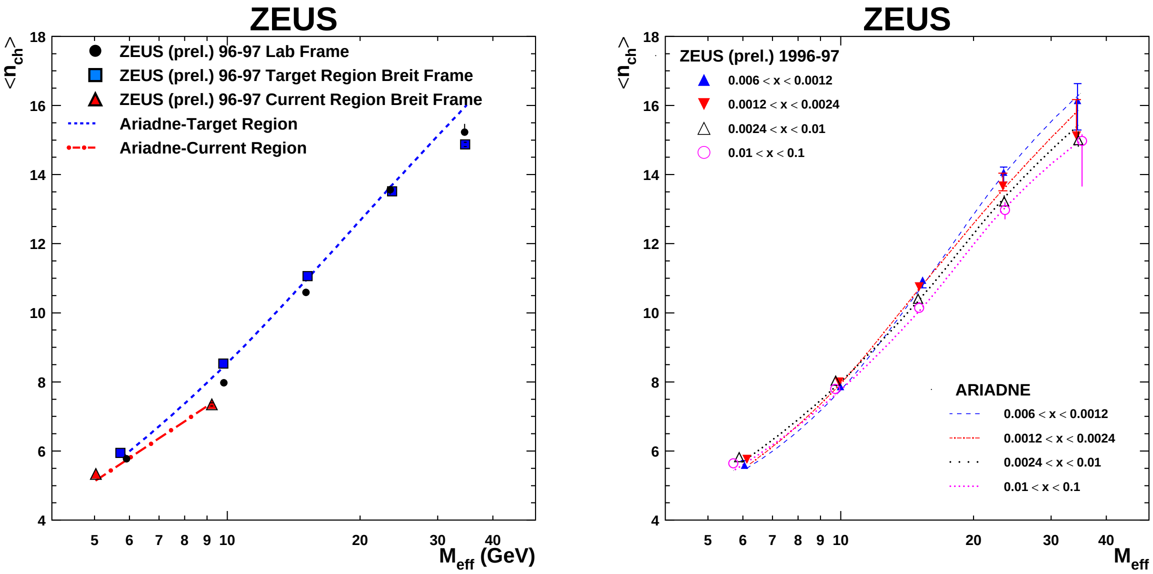

Figure 2: (Left) $\langle n_{\rm ch}\rangle$ in the current and target regions of the Breit frame versus the $M_{\rm eff}$ of the respective (charged + neutral) particles together with the laboratory frame measurement (combined current+target). The predictions from ARIADNE for both regions of the Breit frame are also shown. (Right) $\langle n_{\rm ch}\rangle$ vs $M_{\rm eff}$ for different x regions together with predictions from ARIADNE.

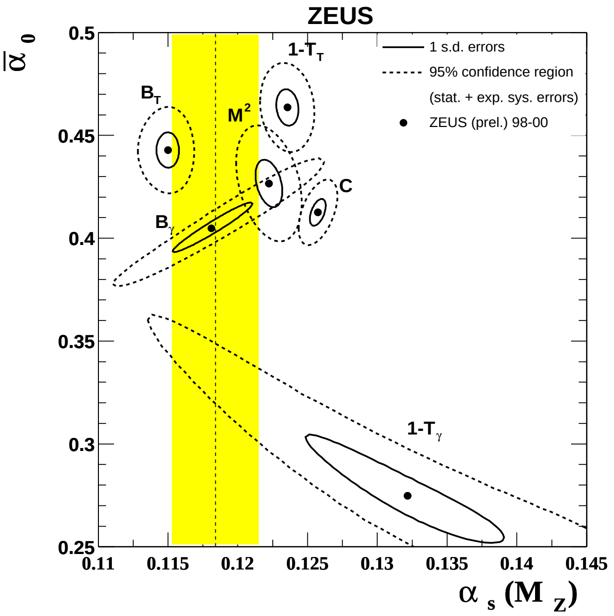

Figure 3: ZEUS extractions of α_s and $\overline{\alpha_0}$ shown in the (α_s,$\overline{\alpha_0}$) plane from fits to the event-shape means. The experimental systematic errors were determined using the Hessian method which takes into account bin-by-bin correlations. The solid curve is the statistical plus experimental systematic 1 σ error contour; the dashed curve represents the 95% confidence limit for α_s and $\overline{\alpha_0}$. The shaded band is the world average of α_s.

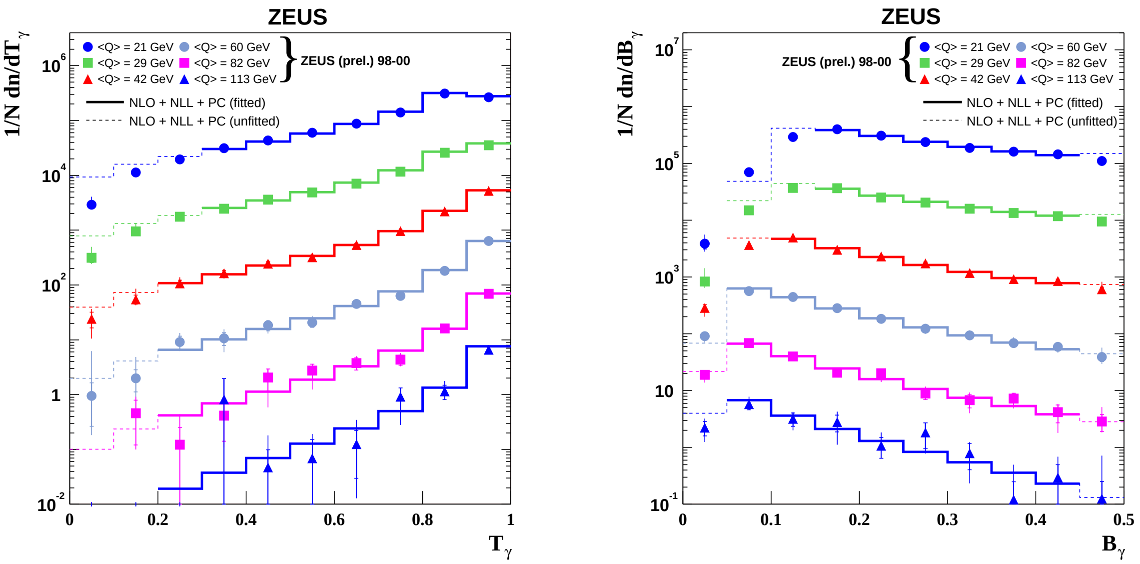

Figure 4: Measurements of thrust (left) and broadening (right) with respect to the photon axis in the Breit frame in different bins of Q^2 compared to the prediction of NLO + NLL + PC, as described in the text. Errors are shown. Solid lines for the prediction represent the fit range, and the dashed prediction line represents the region not fit to the data.

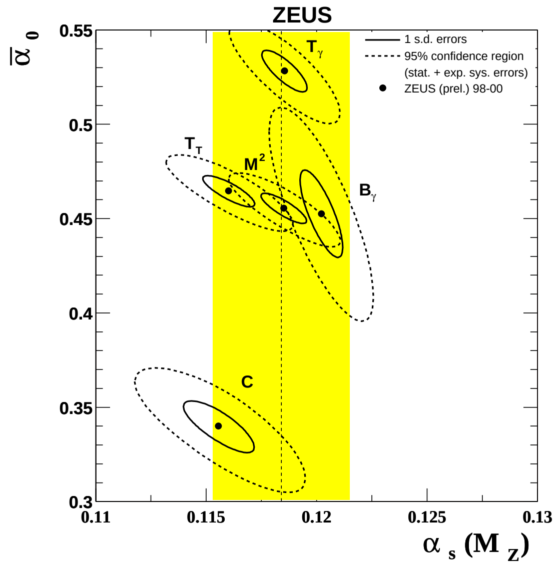

Figure 5: Extractions of α_s and $\overline{\alpha_0}$ shown in the (α_s,$\overline{\alpha_0}$) plane from fits to the event shape differential distributions. The experimental systematic errors were determined using the Hessian method, which takes into account bin-by-bin correlations. The solid curve is statistical plus experimental systematic 1 σ contour; the dashed curve represents the 95% confidence limit for α_s and $\overline{\alpha_0}$.